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Bi H '38

THE PANAMA CANAL

SYSTEM AND PROJECTS

OF

LINDON W. BATES

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Dedication

To my Father, William W. Bates

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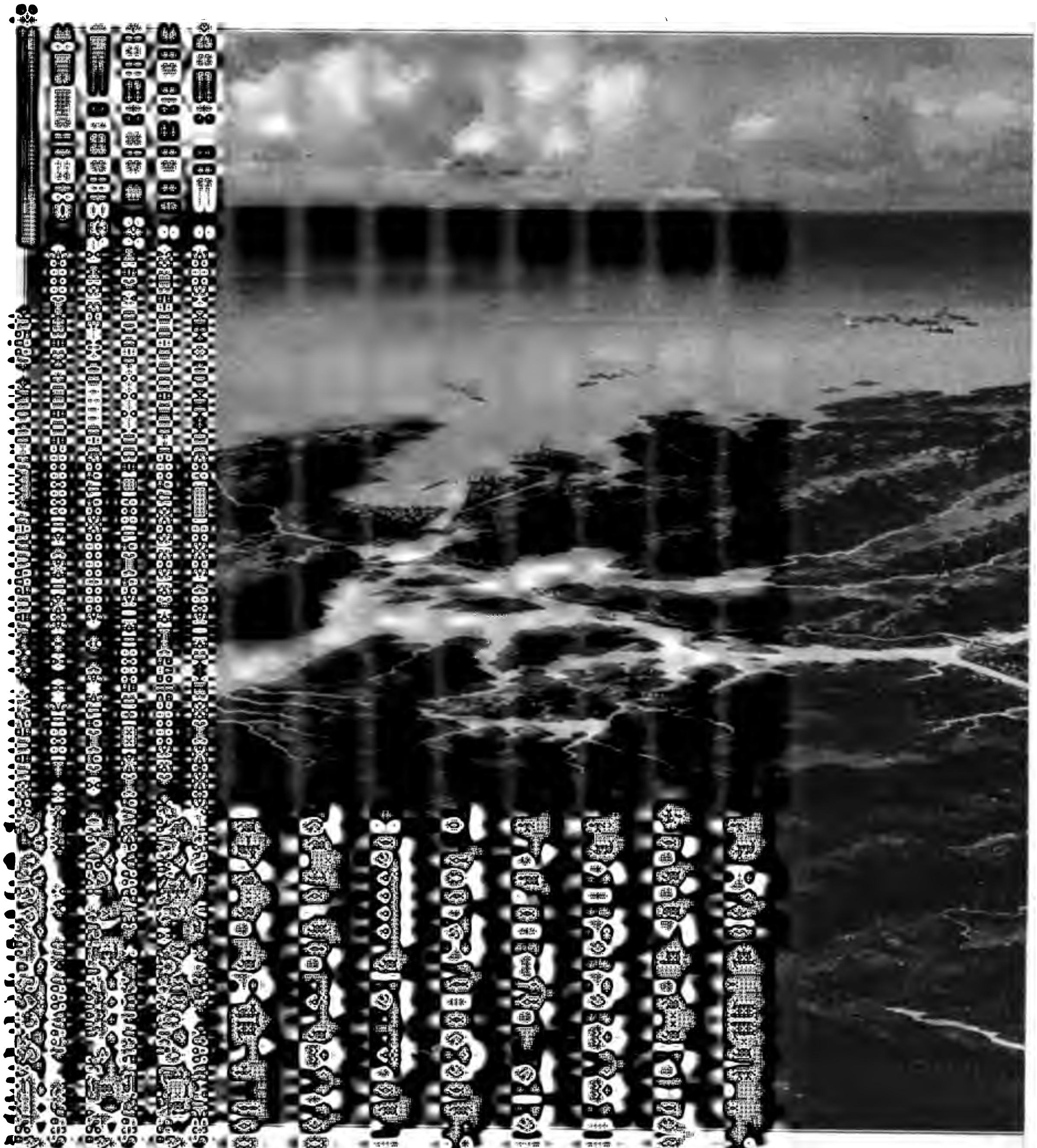
INTRODUCTION.

The Panama Canal is an undertaking of the vastest meaning to America, commercially and nationally. Its construction should be so correct as to leave nothing for present regret or future challenge. It becomes in some measure the duty of every engineer who cherishes his ideal for this great public work to break his silence and reserve if he perceives that in any vital degree or at any remediable point the Canal seems failing of the highest that it can achieve. No one knows more intimately the elements, no one knows more profoundly the difficulties, inherent in this vast problem, than the eminent men, French and American, who, from the inception in 1879 all the way to to-day, have studied and planned by the best in them to solve its perplexities. Let praise go to them unstinted, for this is their smallest due. Believing profoundly, though reluctantly, that the announced methods of solution are not such as to secure to the American people the best, the safest and the most enduring Canal, the writer feels that he would be faithless to his citizenship did he not state so. Knowing further that there exists a more scientific system, it has become his duty as well as his privilege, to set it forth.



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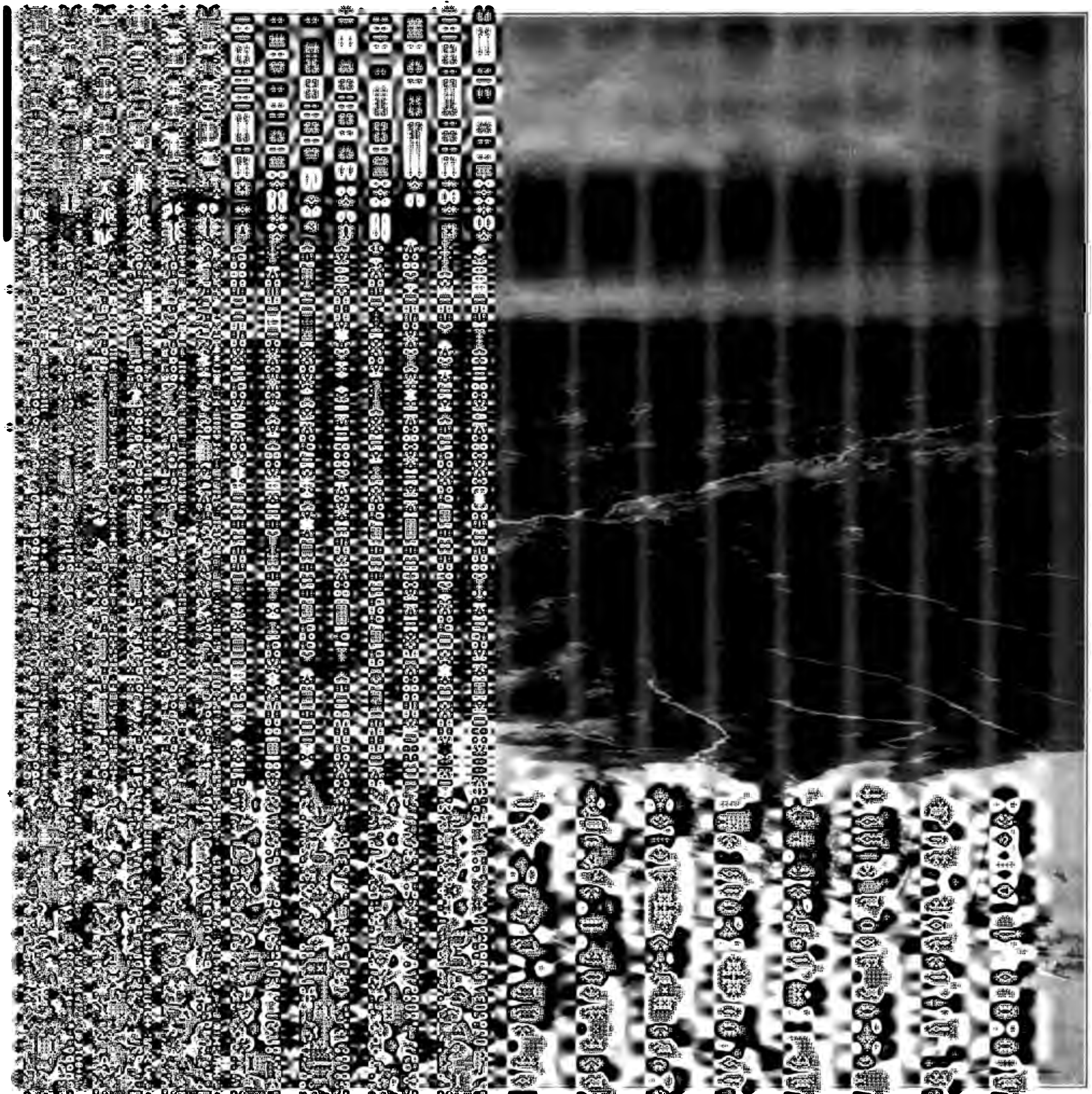

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CHAPTER I.

GENERAL SURVEY.

The Isthmus of Panama, thirty-eight sea miles wide, is traversed longitudinally by a series of hills, whose slopes and intervening valleys make up the watersheds of its dominating river, the Chagres, and of a smaller stream on the Pacific side, the Rio Grande. The hills have been higher, the hollows deeper, the wearing down of the one has filled up the other. A certain topography exists, which is now, for practicable purposes, stable, though the process of attrition under tropic rain and flood still goes on. The hills are covered with dense but low vegetation, which presents an enormous evaporative surface, in excess of a similar-sized body of water. The sun-drawn vapors of the land are always steaming, those of the sea are blown in on every Carribean breeze and are precipitated by the slightly cooler hills. So it comes that at Bohio Gap is recorded the largest rainfall, which diminishes toward the Pacific.

A study of this topography shows that there are four main longitudinal ridges, two parallel with and close to the coasts, two passing down the centre of the Isthmus. The four ridges leave, between them, three valleys, not unlike the spaces between the fingers of a man's hand. These are practically continuous except where eroded through by the Isthmian streams. From these conditions it follows that there are four fundamental engineering ways for making a deep water canal joining the two world oceans, viz.:

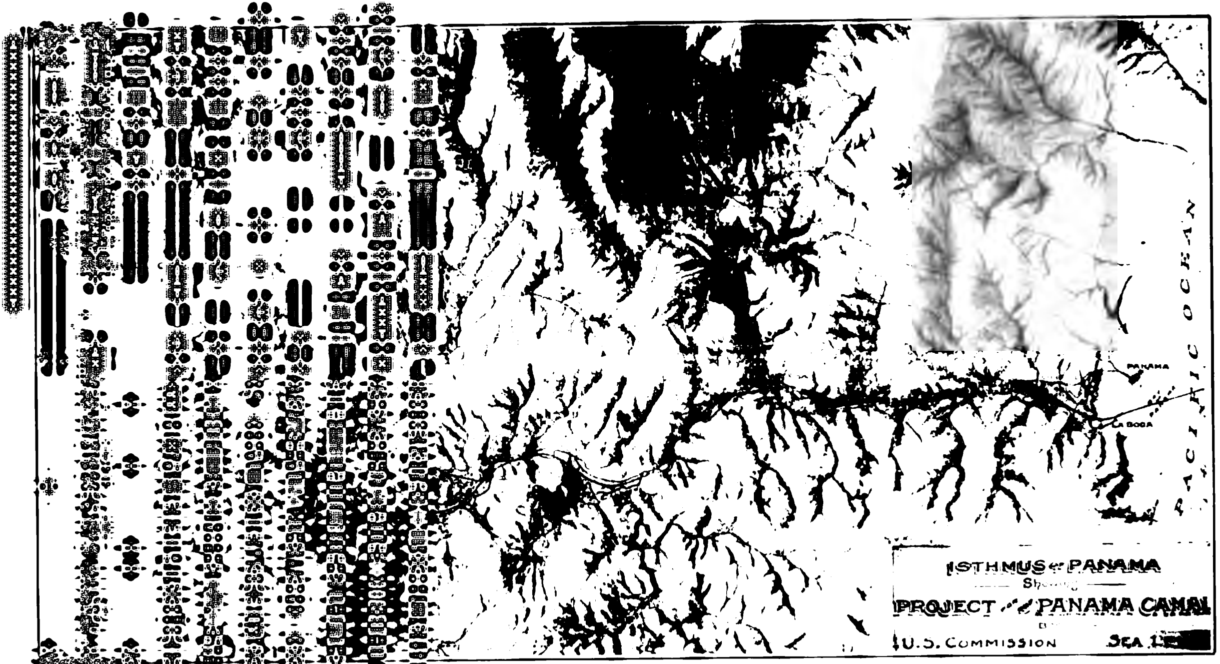
(1.) A sea-level cutting from ocean to ocean through the four ridges.

(2.) Sea-level sections at each end and a high lake between the two central ridges.

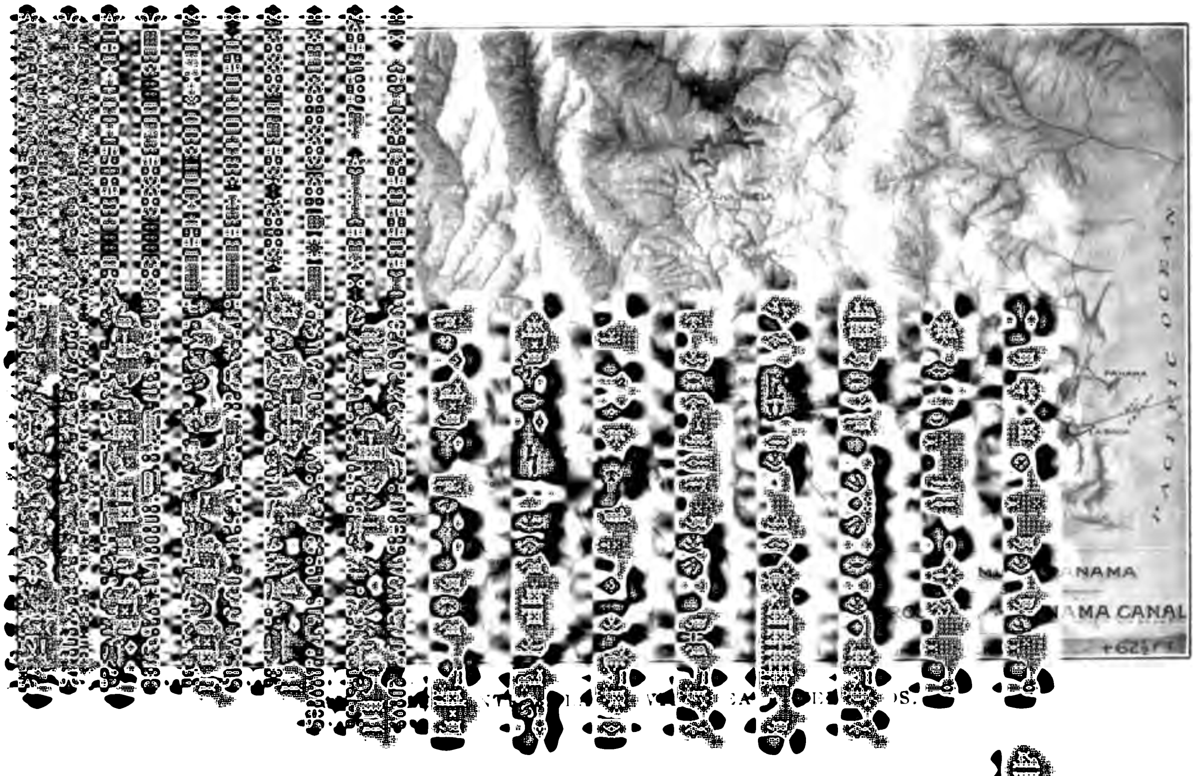
(3.) Lakes in the two valleys next the coasts and a cutting through the central ridges.

(4.) Lakes in each of the three basins.

Every project must come under one of the above heads. There is and there can be no escape from this classification and deduction. These are the only combinations possible to or involved in the physical conditions.



THE SEA LEVEL CANAL.



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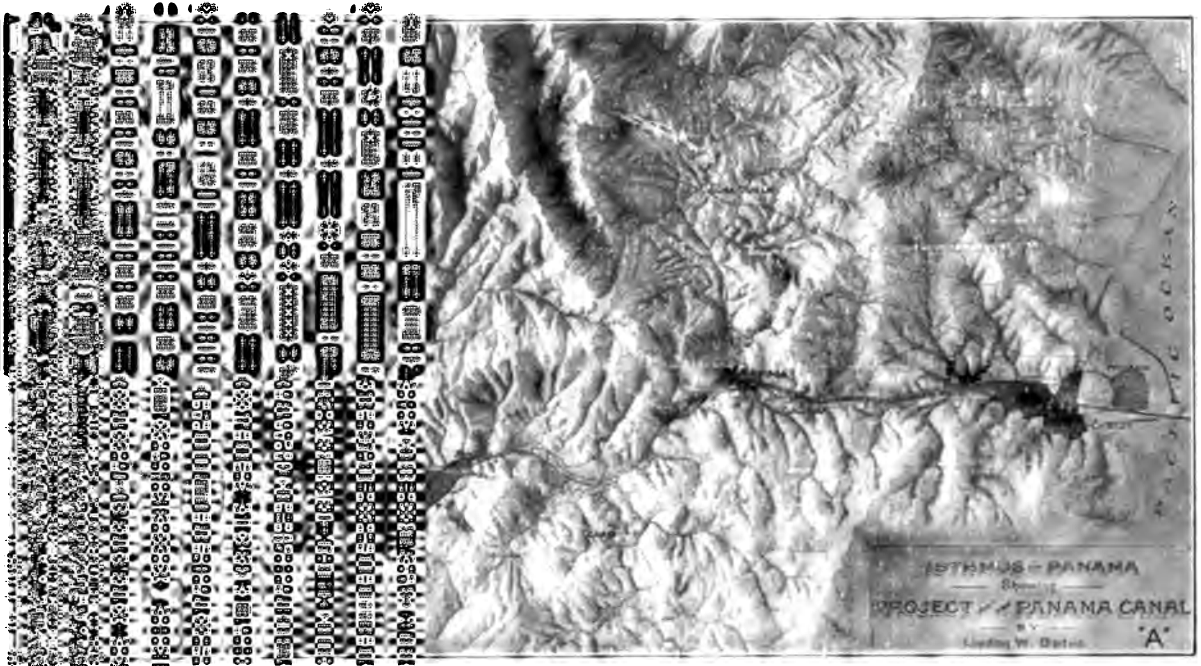
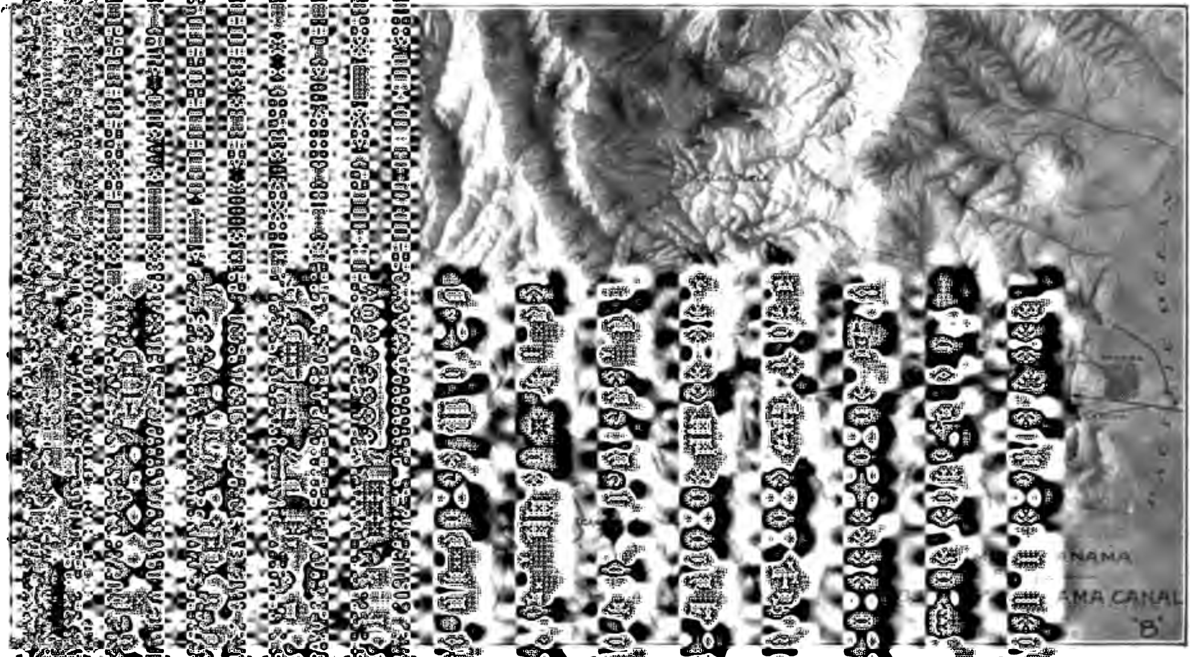


TERMINAL LAKES, SINGLE LEVEL.



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Historically, the precipitate and arbitrary adoption of the first, the Sea-Level scheme, by the Congress of Paris closed the door for the time being against a broad investigation of what could be done and what could be *best* done at Panama.

When the sea-level water-way reached Bohio, across the low swampy valley, financial embarrassment and technical failure loomed straight ahead and the engineers forthwith fell to studying. As a last attempt to save the old Company, the officers planned a canal with the smallest possible further excavation, climbing lock on lock into a lake in the central valley and then even higher across the Culebra ridge at an elevation of 130 feet. It was a plan of desperation, made when panic had begun and when men turned every way for some escape. But the debâcle came and with it fell the idol and the ideal of the French.

The "New Panama Canal Company" in 1894 bought up the assets of its bankrupt predecessor and organized with a residual capital of about $13,000,000 It began its examination of the Isthmian Situation through the so-called "Comité Technique," which reported in favor of a canal at a 97.5 foot level, with eight locks, a 29.5 foot depth and a 112 foot bottom width in the Culebra cut. Their alternative 61.5 foot level with channel dimensions increased to a 35 foot depth and a 150 foot width, is generally held as the best representative of their plans. The main feature of this plan was its two lakes, one at Bohio, navigable for about 12 miles, the other at Alhajuela, serving as a reservoir. Under it the surplus Chagres waters were to be discharged by a spillway at Giganté, and be led to the sea partly down the old Chagres Channel, partly down diversions paralleling the Canal.

In the nature of the case, however, and as the records reveal, these studies did not begin at the beginning and include the complete situation, the whole Isthmus; they embraced only the section of immediate disaster, the great Culebra division. Sea level ends of small dimensions already existed. Prestige and a money credit had to be maintained, and the French engineers within these hemming and compelling barriers evolved and recommended ably and wisely the best plan under the second fundamental alternative. As the engineering saviors of a commercial enterprise, they could not do otherwise than accept the Colon-Bohio and the Panama-Miraflores sections as to be finished at sea-level and therefore out of discussion. There was no money to permit a contemplation of anything but a connection between these excavated ends, and that connection was just as inevitably, of small prism. Here, again, the door to a broad study was closed by force of circumstances.

Next came the American Isthmian Commission of 1901. This reported for a five-lock, high-level canal. The plan differed essentially from that of the

Comité Technique only in its higher proposed level,—85 to 90 feet—and in the fact that it contemplated but one lake above Bohio. The main feature of this project was the famous Bohio Dam with foundations to be sunk 128 feet below sea-level. The head of water was to be 90 feet at the dam which impounded a lake navigable for about 12 miles.

Diversions on the lower Chagres and a Spillway at Giganté were contemplated. The Commission sought to better the plan of the Comité Technique, but they made no radical or vital departure and sought no new interpretation for Isthmian elements. The central mass of the great Culebra appears in Panama history to have acted as a loadstone which drew and held the minds of men. This Commission, likewise, saw apparently but one way, the beaten path along which the French had advanced, and they, too, followed it straight into the unsounded pit at Bohio. The essential explorations had not yet been made and the full knowledge of the physical facts had not yet come.

The Commission reported for what they held to be the best canal and estimated its cost at $144,233,158. Congress provided $145,000,000.

On the basis of this 1901 Commission's plans, the purchase of the French Company's properties was consummated for the sum of $40,000,000, the Panama title was secured and $10,000,000 was appropriated to initiate work on the American Canal. But cost was not the guiding note of the enactment. Congress embodied in the dry legal phraseology of the Spooner Act, the ideals of a century of national aspirations. The Executive shall cause to be constructed a canal.

> "Of sufficient capacity and depth as shall afford convenient passage "for vessels of the largest tonnage and greatest draft now in use, and "such as may be reasonably anticipated, and shall be supplied with all "necessary locks and other appliances to meet the necessities of vessels "passing through the same from ocean to ocean; and he shall also cause "to be constructed such safe and commodious harbors at the terminals "of said canal, and make such provisions for defense as may be necessary for the safety and protection of said canal and harbors."

The creation was to be worthy of the country.

Then came the first comprehensive explorations and borings of the sites at Bohio which were fundamental to all preceding designs. The time had come, the pregnant, crucial time, when the geologic gorge was truly sounded. The way of the Comité Technique,—the sea-level ends and high central lake scheme,—and the adopted plan of the 1901 Commission, stopped short before the fateful Bohio chasm. The rock which their gigantic high-head dam and impounded lake required imperatively, was shown not to exist within the limits of safe reach, and the projects found themselves crumbling upon their foundation-groping caissons.

Those to whom the first two alternatives were alone apparent, deemed the Canal forced back to the historically disastrous, yet much sought and much idealized sea-level. Indecision and uncertainty reigned. The last commission sat for a year and was dissolved without having reached, as a whole, any decision whatsoever. The Engineering Committee of three members, together with its Chief Engineer, went back to 1879 and recommended anew De Lessep's Sea-Level Canal. This is the latest official proposal. It contemplates a channel at mean ocean-plane with one lock, a tide lock, at Miraflores, a high dam at Gamboa creating a large lake, and a long diversion tunnel to carry the impounded waters of the Upper Chagres through the broken volcanic formations which encircle its watershed, and along valleys into the Pacific Ocean or Caribbean Sea. Its narrow bed, deep down in an excavated Culebra defile was to be restricted to a depth of but 35 feet, though vessels are even now afloat officially permitted a draft of over 38 feet. Its projected Atlantic entrance was to be at the mercy of wind and current, open to the Northers. Its designed harbors were to be poor and small, and the gigantic sum of $230,500,000 estimated for its completion was $85,000,000 beyond the amount stipulated for when the purchase was authorized.

From the year 1879 to the present no perception whatever seems to have arisen in anyone anywhere of the other possible combinations and of their inherent fitness. The author at this remote day in canal history, first puts them forth. Two terminal lakes, impounded at a level of about thirty feet by low dykes and regulated by sluice barrages, located where the Chagres and Rio Grande pierce the coastal ranges, will make available an open reach of navigation for seventeen and one-quarter miles; utilizing the old French excavations will give at once a 45 foot channel for this distance; will submerge every swamp in the vicinity of the Canal termini. So favorable is the configuration of land at the ruling locations that Lake Chagres can be made by less than two miles and Lake Panama by less than one mile of impounding structure.

By adding to these a central lake, (the fourth fundamentally possible combination), the effective land width of the Isthmus, along the canal axis not submerged, becomes but nine miles.

These lake dispositions are one of the two keys to the new system herein proposed for the Panama Canal. The other is the empty Basin and Divided Channel Control of the Chagres. As there are inherently four general canal alternatives two of which have never before been presented, there are likewise two methods of disposing of the Chagres River, only one of which, the Solid Dam and Spillway System, has been heretofore considered.

The first method which occurs in every previous plan is that of impounding a deep lake, large enough to hold additionally the volumes which floods may pour in upon it. The making of such a lake has necessitated the great dams in which have centered so much controversy and distrust. These massive, lofty structures are not unprecedented as engineering feats, but in this case there can be found no available rock on which satisfactorily they can be based. The crux of the situation is therefore, this fact, that under tropic conditions no certain reliance can be put on the natural and inevitable requirements for such high dams at Bohio or Gamboa.

Under former designs, again, while the limited water supply of the Canal was secure, all surplus was to flow down parallel to the Canal, partly in the old river bed, partly in the extensive diversions made necessary by the fact that the canal crosses the river a score of times. Thus from the upper basin there would extend to the Atlantic three channels, one the Canal, the others occupied by the torrential Chagres, separated from it by only narrow septa; there would have to be prepared, therefore, parallel waterways, one for the world's shipping and others for the unharnessed river. In the latest sea-level scheme the surplus is to be drained from a high-head lake through a 3¼-mile tunnel, piercing, as is officially noted, "probably through rock varying from soft limestone to medium hard basalt," and returning to the canal district 7½ miles from its Atlantic terminus.

The other alternative for harnessing the Chagres is the one which the new Project proposes: Empty Basin and Divided Channel control. It embraces a system of sluice dams, behind which are empty basins ready in time of flood to receive and hold the excess river volume that can arrive.

The sluice gates will allow the proper amount only to go into the Canal. When a sudden torrent comes down from the upper Chagres watershed, two empty basins with a capacity of far more than the maximum excess recorded will be ready to receive it. Then as the flood abates, the surplus waters will be suffered to gradually pass out, leaving the basins again empty.

A canal section such as that which the American Commission proposed could not safely pass its volume, if the river were all to flow one way—Atlanticward. But if the Chagres be divided and its waters be sent half to the Pacific and half to the Atlantic there are provided effective channels well beyond what the Commission judged sufficient. Thus the parallel diversions with their great expense are rendered needless. Such a method of treatment becomes obviously and axiomatically the best and an altogether ideal solution if there be a certitude that no flood can make a sudden and too great increase of current in the two diverging channels. This is a matter to be decided by adequate data of flood volumes and control capacity, and it is demonstrated in detail later.

The third feature of the proposed system deals with the terminal harbors. Commodious deep water ports are vital to the Canal. They should, in location and design, meet completely the requirements of navigation. They should, as stipulated by the Act, provide as well the military and naval bases essential to American pre-eminence in the Caribbean and the great South Seas.

The meagre port works at Limon Bay and La Boca, representing virtually all that has been designed for the terminal harbors, are both inadequate and defective. These arrangements are entirely disproportionate to even present commerce and offer provisions far removed from those contemplated by Congress.

In the new project, breakwaters are designed, whose arms are to enclose the whole harbor of Panama and La Boca and to terminate at the rocky harbor islands. These breakwaters will encircle and create the safest, largest and best harbor of the South Pacific, with scarcely more cost than would be required to get rid of the material by wasting it at sea. A similar provision is made for the Atlantic port. The Canal entrances are changed, straightened and shortened. The important gain can be inferred, in the fact that under the amended alignment, 224° 40′ of curvature are eliminated from the Canal and from entrance to entrance the distance is diminished by 4 sea miles.

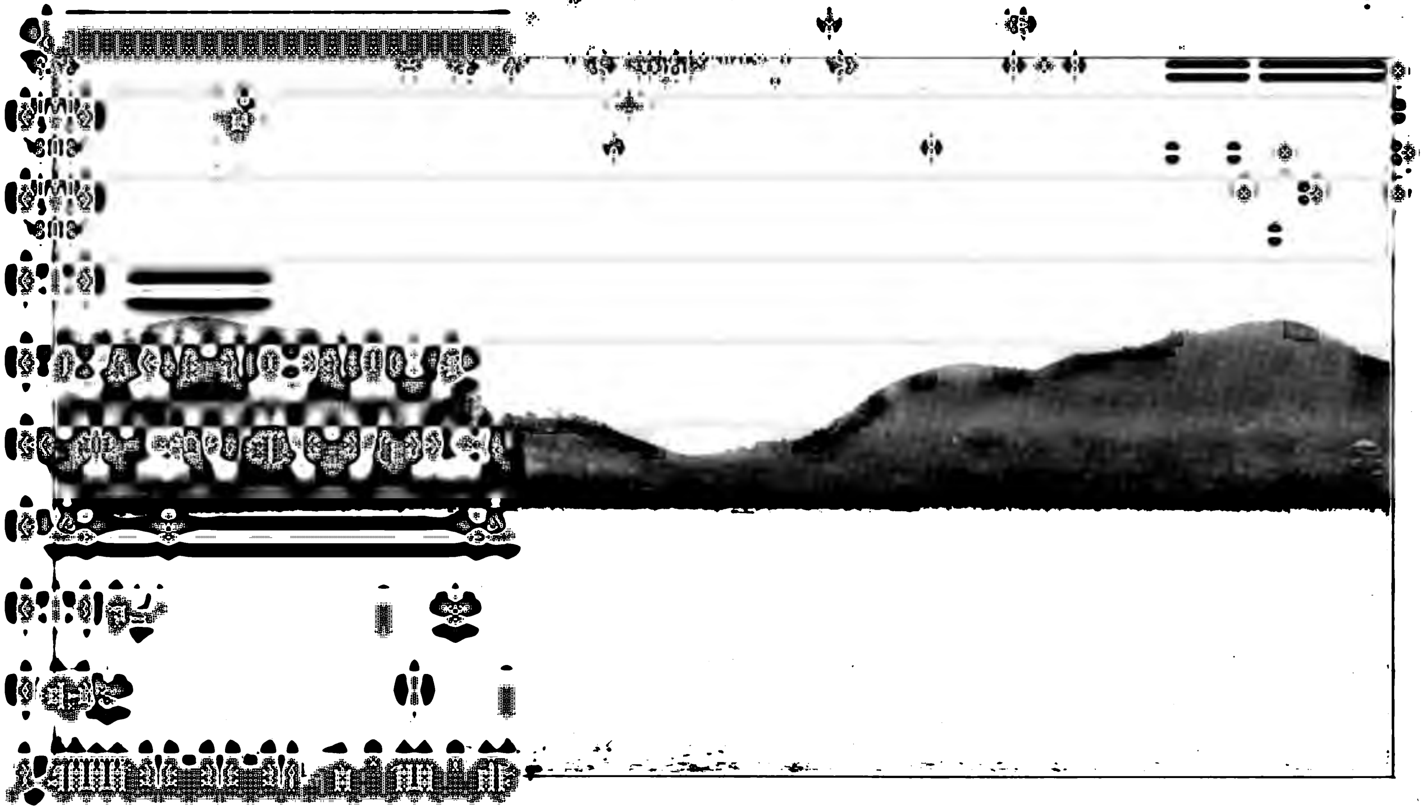
To match the splendid harbors there should be created cities worthy of them and of the great Canal itself.

As the best Atlantic entrance is two miles away from Colon, the new design proposes to abandon the low-lying unsanitary town, lets the Canal end close to Jaramillo Hill and on its hilly slopes founds a new city. At the Pacific terminal the present Panama with its narrow, crooked, crowded streets is ill-fitted to be the Mistress of the Southern Seas. Yet it sits at the gateway and may not be dispossessed. Over the shallows of its Bay, it is proposed to deposit the spoil excavated from the Culebra Ridge, much of which would otherwise be wasted at sea, or be distributed at a heavy toll of life upon malarial swamps. This is the best available deposit ground, and a healthy town site, free from accumulated filth and germs, can be created on a foundation of clean rock. One of the fundamental canal problems has been how to dispose of the material excavated from the great Central cut. The nearest safe spoil area, the flats before the town, have been selected by the new Project because of all that therein becomes possible. The whole of the Culebra can be placed here, out of reach of erosive currents and can serve the splendid future of Panama. Behind the sheltering hills at the new entries can be created the safest possible naval stations. The terminal harbors provided are unique, complete and unexcelled anywhere. A greater Panama and a new terminal city, Balboa, both with twin harbors unrivalled in the whole vast water reaches of the world—these are what this project with its reclamation proposes. Such matchless conditions would be impracticable of realization without the Culebra and other excavations, but waste material may be here transmuted and create great national possessions, a treasury to the Republic of Panama and a glory to America.

These three factors, then, the Terminal Lakes, Empty Basin and Divided Control of the Chagres, and Terminal Harbors of original and strategic dispositions, go to make up a fundamentally new System upon which may be fashioned the concrete plans for the American Canal. It is manifest that such a combination of engineering mechanisms cannot be narrowly conceived as bounded by one or two detailed schemes with metes and bounds of location and dimension. Under the new system, there are possible several plans. The Terminal lakes may be made at a higher or lower level and be discharged at this or that alternative location; the empty basin sluice control can be effected by one or two or three dams at various sites. The terminal harbors may be changed as to breakwater form, alignment or other details. But the principles and the system remain unaltered as a new conception and proposal.

The author has, it is true, specified and developed definitely from all the data available, what he holds to be the best plans under his system. But these are only parts of a greater whole. It is not project A, or B, or any modifications, that go to make up the claim to a new canal. It is the inclusive system of Lakes, Chagres Control and Terminal Harbors whose principles are fundamentally original.

With a view to developing and making clear the full bearings of the wider conception this special presentation has been prepared. In it is given a concise summary of Isthmian conditions. From these are outlined those natural and engineering considerations which ought equally to govern any canal. With the general restrictions placed by nature on the one hand and good engineering on the other, the triune system and its application is developed. The time has come, when the Isthmian riddle can be read in the clearer light of twenty years of unparalleled scientific and commercial advance. The author ventures the belief that he has succeeded in incorporating some of this larger knowledge into his Project for the Panama Canal.



THE ANCON-SOSA SADDLE

CHAPTER II.

FACTORS AND CONDITIONS.

TOPOGRAPHY.

In the confused aggregation of little valleys and isolated hills, rising to the backbone of the Isthmus, there can be traced in the neighborhood of the Canal axis four main crests, the Culebra being the highest. As regards its relations to the future canal, the topography may be best analyzed from the viewpoint of watersheds.

It will be seen that of the three rivers, the Mindi, the Chagres and the Rio Grande, whose valleys the Canal traverses, the dominant factor is the Chagres and its tributaries with the basins which they drain.

The Culebra Ridge is the dividing height of land, separating the Chagres on the Atlantic slope, from numerous small streams, of which the Rio Grande is most important, on its Pacific slope. This ridge was originally 345 feet high. The French have nicked it so that the bottom of the cut is now 280 feet above the sea. The curious geological formation, sliding soapstones and clays near the surface, indurated clays and schists, traversed by igneous dykes below as well as the great volume to be excavated make this divide one of the significant sections.

An extension of the Culebra ridge forms the Pacific rim of the long funnel-shaped basin converging at Gamboa. A sub-basin pinches in above, at Alhajuela, which defines the upper Chagres watershed. This great basin above Gamboa is so well marked that for any project dealing with the control of the Chagres both Alhajuela and Gamboa are ruling locations. The narrowest part of this Pacific rim is apparently on the upper Chilibre waters where at a 132 foot level eight miles of mountain bar the upper Chagres from the Pacific water-shed. On the Atlantic side the rim of this basin forms the divide between the upper Chagres and the Rio Gatuncillo. Its narrowest part is three and one-half miles across at the 132 foot level. This is significant in view of the now reproposed tunnel to carry away surplus water impounded in the Upper Chagres Lake. It will be noted, however, that any waters diverted into the Gatuncillo return to the Chagres near Gatun.

The next natural division of the Chagres basin is the Central Chagres watershed which receives the main stream from Gamboa, the waters of the Rio Obispo, the Rio Giganté and Rio Cano, and a series of small streams issuing from the tangle of hills on the east side. This area discharges through Bohio Gap, the most discussed of all the critical points along the Chagres River.

Below Bohio is the lower Chagres watershed which is crossed by a spur of the South Central or the Bohio range of hills, of which the river gap is Gatun. The Trinidad River, the largest western tributary, drains the valley between the Trinidad Spur and the Bohio Range. On the east side besides the Gatuncillo there is the small tributary, the Rio Tortuoso, as the Trinidad Spur and the Bohio Range between Lion Hill and Bohio unite into one Central Ridge. This makes the Atlantic rim of the upper valley of the Chagres and runs northerly to a junction, five miles back of Old Porto Bello, with the Coast Range, formed by the union of the Mindi and Gatun Hills just east of Limon Bay.

On the Pacific slope, the limit of tide water on the Rio Grande determines Pedro Miguel as a governing situation.

Finally the saddle between Ancon and Sosa Hills, through which a straight line, drawn from Miraflores to the best deep sea entrance of Panama is, owing to this fact, of special significance.

CONCLUSIONS.

A general summing up of the salient points of Isthmian topography reveals the following facts:

1st. That the narrowest place of the Upper Chagres Pacific divide is at Chilibre, which at the 132 foot level is eight miles through.

2nd. That the narrowest place of the Upper Chagres Atlantic divide is on the Gatuncillo and at the 132 foot level it is three and one-half miles through. That the discharge of the Lower Gatuncillo goes to the Chagres, and reaches the vicinity of the Canal at Gatun.

3rd. That the salient points relating to topography affecting the canal are:

Culebra, Main divide.
Alhajuela, First Upper Chagres, constriction.
Gamboa, Limit of Upper Watershed.
Bohio, Limit of Central Watershed.
Gatun, Gap in spur ridge.
Mindi, Chagres debouchments.
Pedro Miguel, Pacific tidewater limit.
Ancon-Sosa Saddle, on direct Pacific sailing line.

GEOLOGY AT RULING LOCATIONS.

CULEBRA.

THE summit ridge known as the Culebra possesses an importance due primarily to the great volume of material which any cut through it must remove. Its formation is of a quite well known character as several shafts have been sunk and a tunnel 2,100 feet long and 20x13 feet penetrates under the main cutting. One deep gash, the cunette, has been made in it by the French. But to complete a fair size prism, so much must be taken from the sides, that this is of small service except as confirming the knowledge about the materials and dispelling the Culebra legend of a slipping mountain. The upper strata include layers of red clay softened by the tropic climatic conditions. Below this is ferruginous solidified mud with layers of hardened red clay. The top layers under the torrential rains have slid into the cut, which though slightly terraced, had no efficient longitudinal drainage. The lower strata are of indurated clay, and soft argillaceous schists traversed by harder igneous dykes.

While walls are perhaps necessary for such material to stand in the underwater slopes, they will probably be found unnecessary above water if the banks are rightly redrained and terraced.

ALHAJUELA.

This constriction of the Upper Chagres valley has been investigated carefully, and been checked over by each Commission, and without question offers the best gap and the most secure foundation for a governing dam of any place along the river. The Chagres at low water is here 92 feet,and a short site exists at this point with solid bed rock 62 feet above sea level.

GAMBOA.

The river here is at a low water elevation of 46 feet above the sea and averages 300 feet wide. The width of the gap at Gamboa is about 5,900 feet on the 200 foot plane. On each side are flats some 400 feet wide, extending to the foothills. The river bottom is of sand and gravel, swept clean by the current. Below this in the geologic gorge comes a sand and mixture with no boulders, and below this, in places occurs soft or disintegrated rock. At the narrowest part the lowest dip of the geologic gorge shows solid basaltic rock at sea-level and it exists close to the center line between the two dominant hills.

BOHIO.

The examinations made in the last year and a half have been conducted with much detail, principally by means of a diamond drill. Sufficient penetration into the underlying strata was made to determine definitely the character of the sub-formation. Borings were taken at short intervals to give the cross sections showing the complete line of bed rock. It has been confirmed beyond peradventure that the rock-sided gorge in this locality is from 163 to 168 feet in depth and that it is filled with an alluvial deposit consisting of clay, gravel, sand and some drift, the material down to 150 feet at least being freely water-bearing. In every alternative location for a dam these similar conditions have been proved. The practicability of using this place for a low head dam depends upon the development of a plan which secures the construction which will sufficiently cut off any flow of water through the alluvial formation filling the gorge.

GATUN.

The Chagres river bed at Gatun cuts through a low spur where the gap at + 120 feet is approximately 6,500 feet wide. This site, too, has been examined in turn by every Commission and the consensus of their reports is that no site for a high dam exists here. Near sea-level some layers of disintegrated rock and indurated clay have been encountered, but no coherent rock line has been found.

There is apparently a deep gorge extending certainly to 175 feet below sea-level without bed rock and filled with alluvial deposits. In general the formation is the same as that at Bohio.

MINDI GAP.

The Mindi Gap lies between the west slopes of the Sierra Quebrancha and the east slopes of Jaramillo Hill—an eminence 385 feet high, rising at the head of the bay and connected with the 400-foot ridge which circles around and forms Point Toro. This Gap has in it several little hills rising to the height of 20 to 50 feet.

At Mindi Gap indurated clay rock is encountered at about 3,000 feet from the shore in the slopes of Jaramillo Hill, through which the French made a *rock cutting* 70 feet in depth. This rock is similar to that found in the old lock sites at Bohio.

The following gives some of the borings taken about the Chagres debouchment.

BORING N.

0 to 15 ft.	Water
15 to 45 "	Silt and mud
45 to 55 "	Loose sand

BORING O.

0 to 8 ft.	Water
8 to 31 "	Silt and mud
31 to 46 "	Loose sand

BORING P.

0 to 2 ft.	Water
2 to 26 "	Silt and mud
26 to 34 "	Blue clay
34 to	Coral rock

BORING Q.

0 to 10 ft.	Water
10 to 37 "	Silt and mud
37 to 47 "	Blue clay
47 to 51 "	Black sand
51 to	Soft brown rock

Boring R.

0 to 3	ft.	Water
3 to 14	“	Silt and mud
14 to 28	“	Blue clay
28 to 47	“	Black sand and clay
47 to		Soft brown rock

Boring S.

0 to 12	ft.	Black sand
12 to 35	“	Soft blue clay
35 to 40	“	Old wood
40 to 50	“	Hard blue clay
50 to 63	“	Hard brown clay
63 to 66	“	Brown rock

Boring T.

0 to 13	ft.	Black sand
13 to 40	“	Soft blue clay
40 to 48	“	Hard blue clay
48 to 50	“	Old wood
50 to 62	“	Soft blue clay
62 to		Soft brown rock

Boring U.

0 to 18	ft.	Black swamp mud
18 to 27	“	Blue clay
27 to 30	“	Fine black sand
30 to 41	“	Hard brown clay
41 to 61	“	Black sand and soft clay
61 to 66	“	Brown rock

(Top 4′ of rock very hard, below that soft.)

Boring V.

0 to 18	ft.	Mud
18 to 25	“	Soft blue clay
25 to 33	“	Old wood and soft clay
33 to 50	“	Black sand & hard clay
50 to		Brown rock

Boring W.

0 to 5	ft.	Mud
5 to 8	“	White sand
8 to 18	“	Soft brown clay
18 to 28	“	Soft gray clay
28 to 45	“	Black clay and shells
45 to 56	“	Fine black sand
56 to		Soft brown rock

Boring X.

0 to 18	ft.	Soft mud
18 to 34	“	Soft blue clay
34 to 46	“	Hard brown clay
46 to 61	“	Hard black sand
61 to		Soft brown rock.

Boring Y.

Near site of possible canal entrance

0 to 18	**ft.**	**Top soil and black mud**
18 to 20	**“**	**Black sand**
20 to 60	**“**	**Brown rock**

Boring Z.

0 to 4	ft.	Water
4 to 24	“	Mud or silt
24 to 42	“	Soft clay
42 to 45	“	Soft black sand
45 to		Soft rock

SOSA-ANCON SADDLE.

The one official record of the composition of this critical location is the old French Company's geological study of the canal axis, which subsequent investigations have shown can be relied on. These data and personal examinations indicate that the two hills are composed of fairly solid traps and schists of the same general character as the rock that occurs at Mindi and crops up near Bohio and in other locations. Since none of the Commissions made any borings on this spot, official knowledge of the formation is not detailed. However, evidence is not wanting to confirm it.

In the construction of La Boca pier in the immediate neighborhood, the caissons were sunk to trap rock, which occurred at a depth varying from 38 to 65 feet below mean low tide.

The various pits, wells, foundations, etc., on Sosa and Ancon Hills, have revealed to a fair degree of certainty that for both hills the basic formations are traps and schist rocks. Overlying the stratified formation, decomposed shales, schists and traps alternate from 1 to 12 inches in thickness. The subsoil is a sea sediment and black loam.

ISTHMIAN HYDROLOGY.

This epitome of studies is directed toward elucidating the water conditions in two main directions. The first is the flood discharge which structures harnessing the river must control, and the low water volumes which the canal structures must in all lock plans make available and adequate for lockage.

These apparently simple demands, in essence requiring data as to maximum, minimum and mean flow, necessitate, however, a long and wide range of investigation. Not only for the main Chagres, but for every stream and affluent that drains down into the vicinity of the Canal, there should be determined definitely and accurately certain primary factors. The general nature of the stream must be known, its bed, its grades, its sediment, its volumes and velocities. It is of small use to base conclusions upon the average yearly volume past, say, Bohio of 4,800 cubic feet per second when this average may be made up of variations between 140,000 c. f. s., lasting for a few hours, and 390, lasting three or four days. The amount of hourly volume must be reckoned with and not at one location but at all the points where material tributaries join. The quantity contributed by every sub-basin through the branches must be allowed for.

Despite the vital necessity for complete information, the Hydrology of the Chagres has received attention up to this time practically only between the junction of the Rio Pequeni above Alhajuela and Bohio. In previous expositions little heed has been given to the régime below Bohio, where two principal tributaries discharge above 57 per cent. of the main Chagres flow. Neither the French nor the United States Commissions have, up to September, 1905, bestowed on the Upper or the Lower Chagres the consideration and analysis necessary to an exhaustive comprehension of the Hydrology in relation to a canal route. The presentation of the most elementary truths about the Chagres, in a clear and inclusive summary, becomes difficult. Instead of an assembling of clean cut engineering observations, the task develops into a weighing of evidence and a finding of the facts amid the disconnected observations which exist in numerous reports.

THE MINDI AND THE RIO GRANDE.

These two smaller streams may be briefly considered. While of some importance as regards silting, they do not offer any difficulties or features that would modify materially the dispositions of any canal.

The Chagres River, however, is of the greatest significance. It must be known from its upper waters to its outlets.

THE MINDI RIVER.

The Mindi drains a very limited watershed on the slopes of the Sierra Quebrancha and Sierra Mindi. It is about 6 miles long.

The Mindi Divide lies between the Sierra Quebrancha on the east and Jaramillo Hill on the west, whose slopes are about 4,500 feet apart. It consists of a group of low-rounded hills, 30 to 70 feet high, with intervening lowlands several feet above sea level. The Divide between the valleys of the Mindi and the Chagres was pierced by the original Canal Company. When the cutting reached the Chagres just below Gatun, a major portion of this river's waters went to Limon Bay via the canal and lower end of the Rio Mindi, occasioning during the last 17 years, a considerable silt deposit in the canal bed and at the head of Limon Bay.

RIO GRANDE RIVER.

This stream, heading on the Pacific side of the Culebra Divide, meets tidewater just above Miraflores, where there is a 5-foot tidal influence. Its watershed above La Boca embraces 85 square miles. The drainage of 10 square miles is held by a dam south of Culebra station, forming the reservoir for the new water supply of Panama City.

DISCHARGE.

Tributaries.—The tributaries of the Rio Grande, whose general course is from N. W. to S. E., are the following small streams:

On the East side:

Rio Pedro Miguel,
Rio Caimialle,
Rio Cardenas,
Rio Curanda,

On the West side:

Qua Mallejon,
Rio Cocoli,
Rio Velasquez,
Rio San Juan,
Rio Farfan.

The maximum, average and minimum monthly fresh water discharge of the Rio Grande watershed is estimated approximately as follows:

Maximum Discharge	8,614 c. f. s.	(estimated)
Mean Discharge	325 c. f. s.	(estimated)
Minimum Discharge	0 c. f. s.	(observed)

THE CHAGRES AND ITS TRIBUTARIES.

Rainfall and Run-off. It was developed in previous studies that there are certain critical points in the Chagres River system, at which observations are logically focused. These places are Alhajuela, Gamboa, 9 miles below, and Bohio, 14 miles below Gamboa, and the Chagres debouchments.

Daily measurements have been taken of the flow of the Chagres at Bohio and Gamboa since 1889 and at Alhajuela in 1895 and 1896, and since April, 1899. The mouths of the Chagres are logically ruling points, but as almost no observations have been taken below Bohio, water discharge determinations for this lower Chagres watershed must be calculated. Taking the area of the Lower Chagres watershed, and establishing the percentage of rainfall that flows off, the discharge may be fairly reckoned. Data exist for such calculation. Rainfall records have been kept at Colon for 33 years, and at Bohio, Gamboa and Alhajuela during the periods when River gauging records have been made. By these means a fair conception may be gained of the discharge at all the ruling points. Where rainfall calculations and discharge gaugings are available, they can be checked one against the other.

The first vital concern is to get the rainfall run-off ratio. This can then be used to get the discharge at the Chagres outlet. In other respects, too, the amount of run-off from a watershed is of importance. The problem here is to learn what average percentage of the rain falling on the watershed under local conditions flows off via the Chagres. In the United States or Europe many observations of stream flow are on record, and percentages of run-off are fairly well determined, but in tropical countries, differing greatly in rainfall, evaporation, and surface conditions from temperate regions, very few data exist. The writer examined the various authorities, and the long series of observations of stream flow and rainfall which have been made at Panama, and hoped that a valuable contribution would have been made on the run-off of tropical watersheds, but authorities differ seriously.

There are three elements involved in computing the percentage of run-off, the rainfall, the discharge of the stream and the area of the watershed.

RAINFALL.

For the first factor, a number of disconnected observations exist. In various locations at various times there were spasmodic records kept and from them a fair idea of conditions can be gained.

The areas for rainfall comparison have been taken as defined by the ridges on the Atlantic, Interior, and Pacific Watersheds and Sub-divisions. It is a natural law that rain clouds on meeting a mountain range are more or less discharged of their contents. Watersheds rather than the arbitrary rain zones marked out with isometric lines as heretofore are employed.

Furthermore the author considers the rainfall and area data of the whole Isthmus so that standards may be deduced for every critical point as well as for the limited superficies of Chagres River Valley above Bohio. The following are made by averaging all data of a series at the given point.

RAINFALL.

French Records, F., U. S. Commission Report, C.

Inches per Annum.
Pacific Watershed.

	Panama.	La Boca.	Pedro Miguel.	Culebra.
1879 to 1882. .	69.52			
1894 to 1889...		73.40		79.60 C 85.3 F 82.45 Av.
1885 to 1888...				
1900............			82.34	

Average rainfall of Pacific Watershed..................................76.95

UPPER CHAGRES WATERSHED.

	Las Minas.	Salamanca.	Sta. Barbara.	Alhajuela.	Gamboa.
1885 to 1900					94.2 F 93.58 C. 93.89 Av.
1900.........	116.22	100.95	113.18	109.19	78.60

Average rainfall of Upper Chagres Watershed.1885 to 1900 ....101.5
" " " " " 1900.........................103.63
Culebra Divide average.. 88.17

CENTRAL CHAGRES WATERSHED.

Place.	1900	Average.		Years.	Averages. C.	Averages. F.	Max.	Min.
Gamboa.....	78.60	94.2	F	21			('87)	('89)
		93.58	C	13	93.58	94.2	136.19	75.72
Culebra......		79.6	C	3			('86)	('88)
		85.3	F	5	79.06	85.3	98.97	64.25
							('93)	('84)
Bas Obispo..		89.3	F	10	89.3	89.3	123	74.71
Gorgona.....		96.4	C	3	96.4	96.4	......	......
Bohio.......		146.01	F	7			('98)	('99)
		155.01	C	3	155.0	146.1	204.61	118.98

Average rainfall of Central Chagres Watershed by F, 102.2 inches.
" " " " " " C 102.77 "

LOWER CHAGRES WATERSHED.

	Average.	Years.	Year.	In.	Max.	Min.
			('98)	=204.61		
			('99)	=118.98	('98)	('99)
Bohio..........	146.01 F	7	1900	=131.93	204.61	118.98
	155.01 C	3	('98)	=115.55		
			('99)	=133.02	('71)	('84)
Colon..........	129.25 C	33	1900	=116.06	168.50	86.54

Average rainfall of Lower Chagres Watershed, 137.67 inches.

MAXIMUM MONTHLY RAINFALL.

Place	Mo.	Year	Inches	Place	Mo.	Year	Inches
Colon	Nov.	1862	43.01	Gamboa	Nov.	1887	24.06
	"	1870	32.42		Oct.	1884	22 36
	"	1887	31.81	Bas Obispo	Oct	1893	19.84
Bohio	Aug.	1898	38.31		Dec.	1893	19.13
	July	1898	34.96	Culebra	Oct.	1886	20.63
	Oct.	1898	28.23				
Gorgona	May	1897	25.12				
	Aug.	1898	19.88				

SUMMARY.

Mean annual Rainfall on Sub-Basins.

Rio Grande, 76.95, say 77 inches for the Pacific Section.
Upper Chagres, 101.5 }
Central Chagres, 102.6, } say 102 inches for the Interior Section.
Lower Chagres, 137.67, say 138 inches for the Atlantic Section.
Culebra Divide, 88.17, say 88 inches for the Summit Section.
Average for whole Isthmus, 113.2 per square mile.

DISCHARGE DATA.

The first factor used in getting the percentage of run-off to rainfall is the measured discharges at the outlets of the various sub-watersheds. Observations, extending over a long series of years were made by the French Company, apparently with care. Also for a year and a half, parallel observations were made by the Canal Commission. But in comparing the two different sources of gauging for the times when two sets of records were taken, it is seen that there are irreconcilable divergencies. The following tables illustrate the wide variations between the two observations.

DISCHARGE AT CRITICAL POINTS.

ALHAJUELA.

MONTHLY RANGE OF 1900, 1901.

Mean Discharge. Cu. Ft. Per Second.

1900	COMPANY.	U. S. COM.	DIFFERENCE.	PER CENT. U. S. GREATER.
January	1590	1941	351	22.0
February	812	916	104	12.8
March	530	608	78	14.71
April	565	631	66	11.68
May	1430	1588	248	18.5
June	1550	1934	384	24.7
July	2190	3148	958	43.7
August	2820	4094	1274	45.1
September	2150	3101	951	44.2
October	3210	4889	1679	52.3
November	2965	4504	1539	51.9
December	2290	3286	996	43.4
1901				
January	989	1165	176	17.7
February	671	766	95	15.5
March	459	541	82	17.8
April	459	509	50	10.8
May	1554	2050	496	32.12
June	1731	2360	629	36.3
Average of Total	1548	2113	565	36.2
Average 9 Wet Months	2234	3165	931	41.6
Average 3 Dry Months	636	751	115	18.09

GAMBOA.

MONTHLY RANGE 1900–1901.

Mean Discharge. Cu. Ft. Per Second.

1900	COMPANY.	U. S. COM.	DIFFERENCE.	PER CENT. U.S. GREATER.
January	1690	2026	336	19.8
February	810	970	160	19.75
March	530	641	111	20.94
April	565	637	72	12.75
May	1340	1615	275	20.5
June	1940	2426	486	25.
July	3350	4104	754	22.5
August	3565	4692	1127	31.6
September	3070	3750	680	22.1
October	4520	5846	1326	29.31
November	4060	5415	1355	33.3
December	2680	3380	700	26.1
1901				
January	1024	1236	212	20.70
February	671	817	146	21.75
March	459	544	85	18.5
April	459	498	39	8.5
May	1766	2190	424	24.
June	2048	2500	452	22.
Average of total all months	1918	2404	486	25.3
Average 9 Wet Months, 1900 only	2913	3695	782	26.8
Average 3 Dry Months, 1900 only	635	749	114	17.95

BOHIO.

MONTHLY RANGE, 1900–1901.

Mean Discharge. Cu. Ft. Per Second.

1900	COMPANY.	U. S. COM.	DIFFERENCE.	PER CENT. U. S. GREATER.
January	2120	2203	83	3.9
February	1060	1052	9	—0.7
March	740	681	59	— 7.9
April	706	652	54	— 7.6
May	1620	1670	50	3.
June	2860	3185	325	11.3
July	5610	5960	350	6.2
August	5260	5880	620	11.7
September	4770	5190	420	8.9
October	7000	8220	1220	17.4
November	6600	7540	940	14.2
December	3740	4100	360	9.8
1901				
January	1483	1508	25	1.6
February	989	937	52	— 5.2
March	706	654	52	— 7.3
April	565	521	44	— 7.8
May	2296	2400	104	4.5
June	2790	2890	100	3.5
Average of Total, 1900 and 1901	2828	3069	241	3.3
Average 9 Wet Months, 1900 only	4398	4883	485	11.
Average 3 Dry Months, 1900 only	835	795	40	4.7

From this comparison one deduction of value can be made. This is that there must be allowed in all observations a margin of safety which for conservative practice must be figured in the least favorable aspect. There is absolutely no existing way for telling which is right. No nice deductions as to run-off can therefore be final and conclusive. The French observations were taken over a long period of time. It is wiser to build upon the extended average so obtained and in due season to employ a factor of safety than upon a shorter average from the United States Government Records.

AREA.

While care was apparently exercised in getting rainfall and discharge data, the third element, area, has in discussions purporting to be authoritative, been merely surmised. For the whole area above Bohio the American Commission statement is 126 per cent. of the figures derived from French sources and for the watershed above Alhajuela 157 per cent. When such differences as these exist one or both must be questionable.

Comparing the published areas, the following is shown:

TOTAL WATERSHED AREAS.

	NEW PANAMA CANAL CO.	U. S. COMMISSION, 1901
Above Alhajuela	320 Square Miles.	505 Square Miles.
Gamboa to Alhajuela	130 Square Miles.	130 Square Miles.
Bohio to Gamboa	250 Square Miles.	245 Square Miles.
Total,	700 Square Miles.	880 Square Miles.

These differences, which are little short of amazing in such reports, needless to say, resulted in some curious conclusions. Indeed, the apparent consequences have been a most prolific source of the hearty distrust with which engineers have approached the Chagres regulation problem. One deduction was that there was a remarkable variation between the run-off and percolation from the different sub-basins. The only surmise put forward to explain this was that the ground must be as porous as a sponge, and in general, unlike any other known formation.

A second conclusion was that, "The Valley of this tropical river has 2.5 times the rainfall, about 3.2 times the outflow and about 1.5 times the evaporation characteristic of the Northeastern portion of the United States."

But these remarkable variations in estimates of run-off for the different sub-basins of the Chagres from watersheds that physically are identical so far as any one can see, and this unique behavior of the Chagres, which seems like any other tropic stream, should have led to a verification of the data. But to the present time this evidently has not been done. Despite these differences, which seem, to have escaped criticism because the obvious comparisons to check results were never made, the engineering public has taken as standard apparently all the conclusions based on the French Company's data.

It is clear that some standard is needed here. For various reasons inherent in the evidence of the reports, the author has used the areas which he believes to be fairly accurate.

The figures of the French calculations are probably correct for the territories they surveyed and worked in—the Bohio and Lower Chagres basins. For the district above Alhajuela both authorities estimated and the United States Commission was nearer right. It had also an independent source for its figure, for, in connection with surveys of the Darien Route, the position of the remotest Eastern crest of the Chagres Valley was observed and the area of the upper valley deduced by the U. S. Hydrographer in 1901, with a reasonable presumption of correctness. The revised areas are as follows:

WATERSHED AREAS.

	AREA IN SQUARE MILES.		
	U. S. COM. 1901	FRENCH SOURCES	REVISED 1905
Upper Watershed, above Gamboa:			
Upper Chagres above Pequeni	300	..	300
Rio Pequeni	175	..	175
Between Alhajuela and Pequeni	30	..	30
Between Alhajuela and Gamboa	130	130	130
Central Watershed between Gamboa and Bohio:			
Chagres Basin, Gamboa and Bohio	245	250	245
Rio Obispo	38	...	38
Rio Cano	...	...	90
Lower Watershed, Bohio to Sea:			
Chagres Basin, Bohio to Mindi	520	...	500
Rio Grande Watershed:			
Above Pedro Miguel	...	...	10
Rio Pedro Miguel	...	...	19
Pedro Miguel to La Boca	...	...	56

TOTALS.

Chagres above Alhajuela	505	320	505
above Gamboa	635	450	635
above Bohio	880	700	880
above Chagres-Mindi Outlets	1400	...	1380
Rio Mindi	...	...	20
Rio Grande	...	...	85

The conclusions herein reached are purely the results of sifting evidence, using such independent data as could be procured, and a test might profitably be arranged for these deductions. Such a test may be applied by finding the outflow ratio in the revised areas and comparing the results with known and normal conditions elsewhere.

The following tables summarize the results:

RAINFALL OUTFLOW RATIO

	BASIN ABOVE BOHIO—885 SQ. MILES			BASIN ABOVE GAMBOA—635 SQ. MILES			BASIN ABOVE ALHAJUELA—505 SQ. MILES		
	OUTFLOW IN.	SIX YEARS RAINFALL IN.	RATIO P. CENT.	OUTFLOW IN.	SIX YEARS RAINFALL IN.	RATIO P. CENT.	OUTFLOW IN.	FIVE YEARS RAINFALL IN.	RATIO P. CENT.
Jan.....	5.64	5.78		5.26	3.90		5.08	4.25	
Feb.....	1.68	1.06		1.74	0.91		1.84	1.10	
Mar.....	1.17	1.34		1.43	1.06		1.44	1.10	
Apr.....	1.49	2.95		1.92	2.56		1.84	2.28	
May....	2.74	10.47		3.26	10.63		3.23	11.18	
June....	3.76	10.63		4.20	10.43		4.22	10.51	
July....	5.72	15.51		5.73	15.79		5.30	15.99	
Aug.....	6.40	14.21		6.64	13.07		6.42	12.83	
Sept....	5.80	11.45		5.88	10.35		5.59	12.05	
Oct.....	7.55	14.21		7.09	15.16		6.66	14.25	
Nov.....	10.80	17.01		8.84	16.89		8.27	18.90	
Dec.....	6.14	6.92		6.05	6.69		6.80	7.47	
	58.89	111.54	52.8	58.04	107.44	54.0	56.69	111.91	50.7

By making a similar percentage calculation for the earlier figures it is seen that in the ratio involving the Alhajuela basin, where the area was taken, it is considered too small, the ratio is far above that on any other parts of the Isthmus. But the true ratios are normal. The table below shows the difference:

RAINFALL OUTFLOW RATIO

BASIN	RAINFALL IN.	OUTFLOW SMALL AREA	SMALL AREA RATIO PER CENT.	OUTFLOW CORRECTED AREA	CORRECTED RATIO PER CENT.
Above Alhajuela, 5-year records..	111.91	89.51	**80.**	56.69	50.7
Alhajuela-Gamboa 5-year records.	98.08	56.73	57.8	56.73	57.8
Above Gamboa 6-year records....	107.41	81.90	**76.2**	58.04	54.0
Gamboa-Bohio 6-year-records....	114.54	58.53	51.1	58.53	51.1
Above Bohio, 6-year records......	111.54	73.44	65.8	58.89	52.8

These results are consistent in themselves, prove that the Chagres is a normal river, and that the revised estimates of real or equivalent watershed above Alhajuela are practically correct despite calculations to the contrary. Furthermore, they bear a relation to the ratio on temperate rivers, such as would be naturally expected. The average yearly percentage of run-off of rainfall for various streams in the United States is given in the table below:

River	*Ratio*
Sudbury	48.6%
Cochituate	43.2%
Connecticut	56.5%
Croton	50.8%
Upper Hudson	59.0%
Passaic	54.0%
Perkiomen	49.2%
Tohickon	56.7%
Neshaminy	48.5%
Savannah	43.1%

It would thus seem that there is practically no difference in percolation at Alhajuela, Gamboa or Bohio and that the percentage of run-off of the Chagres watershed is only slightly in excess of that for streams in the United States.

Having verified somewhat the data, we can generalize upon their significance.

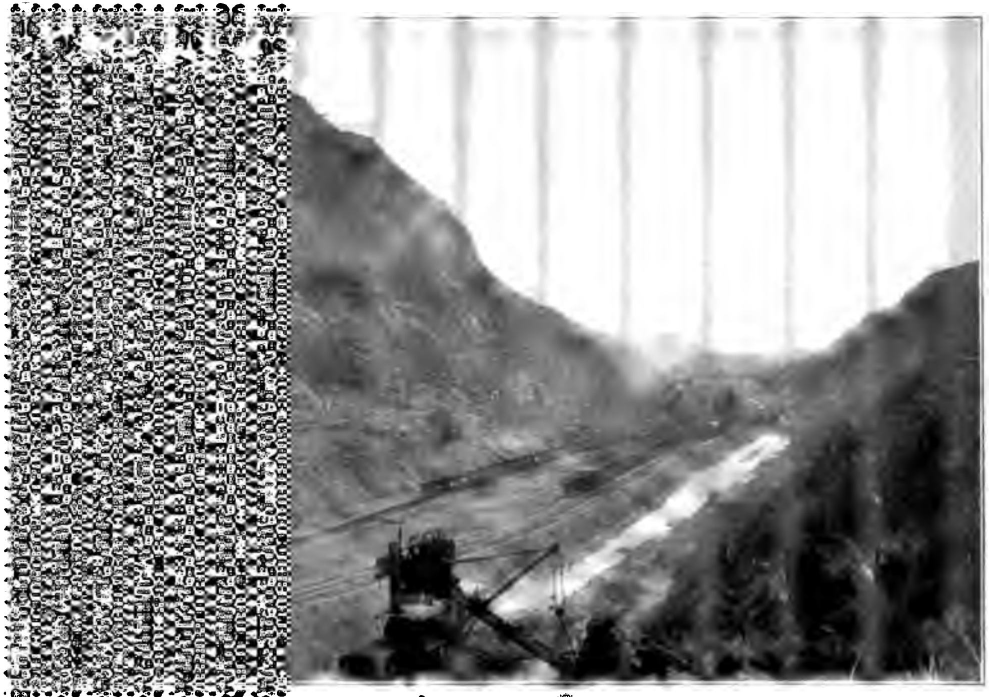
The rainfall and consequent run-off, whose ratio is fairly constant, is on the Pacific watershed 75 per cent. of that in the Upper Chagres and Central watershed. On the Atlantic side, which includes the Lower Chagres, it is 135 per cent. of the interior belt.

Or, to put it in another way, the rainfall and run-off of the Pacific Slope is about a quarter less, and those of the Atlantic Slope, 35 per cent. more per square mile of watershed than that of the valley above Bohio. Similarly these factors for the Culebra Section are 86 per cent. of the Interior Section.

A further inspection of records discloses that generally speaking the maximum recorded annual rainfall at an observatory here is about double the minimum. The greatest yearly rainfall of record is 204.61 inches in 1898 at Bohio where the average is about double that of the Pacific Slope and 50 per cent. higher than the average of the valleys above Bohio and above Gamboa. Bohio likewise shows the highest monthly averages except the record of 43.01 inches at Colon in 1863. According to the only data available as to the Atlantic Slope it is manifest that the rainfall and run-off per square mile of the watershed below Bohio is over a third greater than that above this Gap, a fact due doubtless to the effect of the Bohio or Central Ridge on the moisture-laden winds from the Caribbean Sea.

It is likewise a matter of note that the locations of the maximum rainfall in any month or week, or day, are most varied. A deluge seems sure some time [illegible] heavy separate downpour means a river rise and freshet [illegible] starting from its locality. General rains, filling all [illegible] sly mean a flood, short lived because the hill slopes and [illegible] teep.

[illegible] dge of conditions entirely dispels the legend that the [illegible] ys is unduly porous; that if a lock canal were undertaken



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The discharge from the Chagres outlet is calculated as follows from observed Bohio discharge:

WATERSHED.	RAINFALL.	AREA.
Above Bohio	102 inches	880 square miles
Lower Chagres	138 "	500 " "

Knowing that the run-off ratio per unit area is approximately the same, the flow at the Chagres mouth contributed by the watershed below Bohio Gap is:

$$\frac{500 \times 138}{880 \times 102} = .77 \text{ of Bohio Discharge.}$$

To this is added the water volume past Bohio and the result is a fair approximation of the total discharge of the Chagres at its outlets.

YEARLY DISCHARGE RECORDS.

In c. f. s.

YEAR.	ALHAJUELA.	GAMBOA.	BOHIO.	OUTLETS OF CHAGRES.
1890	3,211	4,172	6,304	11,164
1891	2,328	3,052	4,476	7,916
1892	3,308	4,314	6,513	11,528
1893	2,778	3,605	7,081	12,538
1894	2,890	3,773	6,098	10,798
1895	2,122	3,055	4,482	7,932
1896	2,089	2,750	4,216	7,461
1897	2,192	2,864	4,830	8,550
1898	2,263	2,987	3,944	6,984
1899	2,051	2,572	3,384	5,989
1900	1,837	2,345	3,509	6,211
1901	1,981	2,391	3,855	6,825
1902	2,278	2,969	4,179	7,396
1903	2,381	3,058	3,958	7,006
Yearly Mean	2,424	3,164	4,798	8,492
Dry Season Mean	965	1,176	1,371	2,425
Wet Season Mean	2,910	3,827	5,940	10,510

Rio Grande	345	c. f. s. Est.
Upper and Central Chagres, Mean	4,798	"
Lower Chagres, Mean	3,694	"
Total	8,837	c. f. s.

CHAGRES FLOODS.

In the measurements of maxima, there is also a wide divergence in the figures given, so much so as to lend concern. The table below exhibits the data available. It is to be noticed that while all the calculations are based upon the French gaugings, the results reached by their exponent are very different from those arrived at by the American Commission. Yet each is quoting from the same original source.

GAMBOA.
c. f. s.

DATE.		CANAL COM. REPORT DD. P. 44, MAXIMUM DISCHARGE.	48 HR. DISCHARGE AVERAGE.	PER-CENT-AGE.	FRENCH SOURCES MAXIMUM DISCHARGE.	48 HR. DISCHARGE AVERAGE.	PER-CENT-AGE.
	1879	....	....	...	78,614	65,250	83
Nov.	1885	57,844	38,034	66	64,488	43,404	67
Dec.	1885	....	....	...	44,923	32,421	72
	1888	57,491	44,849	78	58,132	48,278	83
	1890	58,727	29,416	50	65,371	34,752	54
	1893	42,625	26,803	63	43,086	27,971	65

BOHIO.
c. f. s.

DATE.		CANAL COM. REPORT, PAGE 89 MAXIMUM.	FRENCH SOURCES MAXIMUM.	48 HRS.	PERCENTAGE.
	1879	136,000	112,730	90,184	80
Nov.	1885	....	74,800	....	......
Dec.	1885	....	47,466	....	......
	1888	....	79,000	....	......
	1890	74,998	71,660	51,068	71
	1893	48,975	51,100	43,590	85

A very general idea of volumes can be gathered from this table. But vital information exists which is not so debatable as these quantities. By an analysis of the more probable errors it is seen that while quantities and volumes are easy to mistake, the general duration, date and height of the floods do not require such technical and scientific treatment and so these facts are apt, in the nature of things, to be fairly accurate. From these inherently reliable observations the following results are obtained.

As to the frequency of floods; the Panama Railroad records, kept for fifty years back, mention none previous to that of 1879, as doing damage to the line. In 1879 there occurred the greatest rise known, and since then five have been recorded, all discharging over 40,000 c. f. s. past Gamboa. Discharges of over 70,000 c. f. s. are very rare.

Their duration is likewise well observed. That of Nov., 1885, rose from a level 6.5 above low water, reached its maximum, 31.50 feet above low water in 36 hours and fell in a few hours to 10 feet level. Five days afterwards the river rose again in the flood of December 3–5, lasting about 48 hours.

That of 1888 rose from only some 2 feet above low water, reached its highest point in 48 hours and subsided in another 48 hours. It was above the 10 feet stage for 128 hours.

The flood of 1890 was marked by a rise at Gamboa of 25 feet in 17 hours and a subsidence of 21 feet in 23 hours. Some 48 hours again marked the limit of high level.

That of 1893 was one of those which was carefully measured by the French Company. Rain to 13.9 inches fell at Gamboa, accompanying a severe storm. The discharge was in 48 hours 65 per cent. of the maximum and came in waves.

It is apparent that in addition to being infrequent the floods are short in duration, rarely exceeding 48 hours with serious discharge volumes.

The great rise of 1879 is of course the maximum determining factor. To get its total volume the roundabout course of comparing it with the known flood of 1885 may be resorted to. By French figures, that of 1888 discharged past Gamboa more than 40,000 cubic feet per second for 42 hours. The maximum momentary discharge has been calculated to be 58,132 cubic feet per second and the average discharge during this time about 49,000 c. f. s. The maximum height above low water was 31.37 feet. It appears from one authority that in 1879 the extreme height of flood above low water was 36.65 feet and the maximum momentary discharge 78,614 feet per second.

Then the discharge of the flood of 1879 past Gamboa would be

$$\frac{49{,}000}{58{,}132} \times 78{,}614 = 66{,}264 \text{ feet per second for}$$

$$\frac{36.65}{31.37} \times 42 = 49 \text{ hours.}$$

While these deductions may be approximate, it is considered safer to take a less favorable figure. The accepted plan for controlling the Chagres must deal with the maximum and have a margin of safety besides; 136,000 c. f. s. is the officially estimated flood that passed Bohio in 1879.

It is not wise to base a vast expenditure on French Hydrographic Records and elaborate deductions therefrom without taking into full recognition and account such percentages of error or difference of facts, where large margins of mistake manifestly may exist. The accepted project must safeguard the

Canal on the basis of the most exacting, not on the most favorable deductions. The maximum standard must be higher than the maxima of the highest estimates—those of the Commission of 1901. No less than 140,000 c. f. s. past Bohio can be taken and all must be accepted which that high water mark involves to the Chagres above and below this point.

The observed flood of 1890 is the best standard of comparison, since Bohio records of that in 1888 are not procurable. It had a discharge of 51,068 c. f. s. for 48 hours and a gauge height of 32.1. Treating this figure in a similar manner with a gauge height of 39.3 taken by the Isthmian Canal Commission, we have for the ratio past Bohio:

$$\begin{array}{l} \text{(48 hr.)} \\ \\ \text{(Max. Disch.)} \end{array} \quad \frac{51{,}068}{74{,}998} \times 140{,}000 \text{ c. f. s.} = 102{,}140 \text{ c. f. s.}$$

$$\begin{array}{l} \text{Max. gauge} \\ \quad \text{for} \\ \text{Max. gauge} \end{array} \frac{39.3}{32.1} \times 48 \text{ hrs.} = 59 \text{ hrs.}$$

The best determination of the momentary maximum at Gamboa has been made during the past year. The gauge height has been proved to be that corresponding to 99,600 c. f. s. The maximum average is about one-sixth less than the maximum momentary, hence it may be fairly assumed from all the evidence that the discharge past Gamboa in 1879 was approximately 83,000 c. f. s. for 48 hours, a result consistent with the evidence and the relations between the records at Bohio and Gamboa. The flood of 1888 at Gamboa was 83 per cent. of that at Bohio.

Freshets of the Chagres.—In this presentation the term freshet is applied to river rises measuring at Bohio under 40,000 c. f. s.

On the average about 20 freshets occur yearly. In the year 1886 there were 43, large and small. These occur at any time during the nine rainy months and, lasting on an average about 20 hours, carry the discharges at Gamboa from its usual rainy season flow of 3,000 to 8,000 c. f. s., up momentarily as high as 30,000 or 40,000 c. f. s. and then subside. A typical one as given by Canal Company records occurred on July 20, 21, 1903. It lasted about 20 hours and during this time discharged on average 20,750 c. f. s. The discharge for 18 hours above 8,000 c. f. s. would give 19,000 acre feet. Elaborate tables have been published in U. S. Official Reports and from data derived from French records. As to ordinary freshet results, authorities are stated to be in substantial agreement regarding the c. f. s. discharge

MINIMUM WATER STAGES.

A final hydrologic determination concerns minima. The following table gives the most reasonable data in this regard. It is necessary here to get minima for the whole Isthmus.

MINIMA UPPER CHAGRES WATERSHED, ALHAJUELA STATION, 1900.

	COMMISSION.	FRENCH COMPANY.	CALCULATION FIGURES.
Yearly	2567	1840	1840
Three Months	718	569	570
One Month	608	530	530
Daily	395	318	310

MINIMA UPPER CHAGRES WATERSHED, GAMBOA STATION.

	U. S. COM. 1901	FRENCH RECORDS 1892–1900 1889–1891	CALCULATION FIGURE.
Yearly	....	2880	2700
Three Months	619	635	620
One Month	498	530	500
Daily	278	388	270

MINIMA UPPER AND CENTRAL CHAGRES WATERSHED, BOHIO STATION.

	U. S. COM. 1901.	FRENCH RECORDS 1895–1900.	CALCULATION FIGURE.
Yearly	....	3400	3400
Three Months	704	795	700
One Month	521	652	520
Daily	255	442	250

MINIMA CALCULATED TOTAL CHAGRES DISCHARGE (177%) OF BOHIO.
Past Gatun it is about the same.

	U. S.COM.	FRENCH CO.	CALCULATION. FIGURE.
Yearly	....	6018	6000
Three Months	1246	1307	1240
One Month	921	1154	920
Daily	451	782	450

To this may be added the Rio Grande Watershed Minima, but the quantity is negligible.

CONCLUSIONS.

Therefore to restate some conclusions:

1. The average yearly wet-and-dry-season flow to be figured on past the ruling points is:

	YEARLY. C. F. S.	WET. C. F. S.	DRY. C. F. S.
Alhajuela	2,424	2,910	965
Gamboa	3,164	3,827	1,176
Bohio	4,798	5,940	1,371
Mindi-Chagres	8,480	10,510	2,425

The above table is from French sources and records, and, as shown, must be used with a factor of safety due to the differences in gauging methods.

2. The flood volumes to be allowed for past critical points are:

	MAX. C. F. S.	AV. C. F. S.
Gamboa	99,600	83,000
Bohio	140,000	102,140

3. Floods of over 44,000 c. f. s. occur about every 10 years and last but 48 hours.

4. Freshets over 10,000 c. f. s. occur 5 times a year on the average and last 20 hours.

5. To take care of the normal flow and freshets but excluding floods, a channel of 15,000 sq. ft. is required.

6. The minimum amount of the whole Isthmus is for purposes of calculation 6,000 c. f. s., which, as was seen, is fairly taken as the lowest likely limit of river flow. This volume will practically all pass Gatun.

7. As to run-off, the Chagres Valley is normal and does not differ essentially from another in per cent. of run-off to rainfall. Percolation is normal and no part of the Valley is underlaid by a sieve-like formation—or any formation which makes either surface or under-ground water at all abnormal.

FACTORS AT THE ATLANTIC TERMINUS.

Here and at the Pacific Canal Terminus, the determination of the most satisfactory solution rests largely upon physical factors, though vested rights and existing terminal facilities also enter into the equation.

LIMON BAY.

Limon Bay is part of an indentation in the Isthmus of Panama from the Caribbean Sea. This indentation lies between Point Toro and Point Hala Remo, some four miles apart. The coral island of Manzanillo divides the bight into two bays—the one to the east known as Manzanillo, that to the west as Limon or Navy Bay.

The bight is surrounded by an amphitheatre of hills which completely shut it off from the Valley of the Chagres and its tributaries. The French Canal cut through the horseshoe range at nearly the lowest point in its crest, Mindi, half a mile back from the head of Limon Bay. This canal connected the bed of the Mindi—a little stream running into the bight, with the channel of the Chagres, and afforded the latter a short cut and a second outlet to the sea. The old mouth is five miles south of Point Toro, where the Chagres through a narrow valley in the Coast Range debouches past a notable promontory on the east bank directly into the ocean.

Limon Bay is three miles wide and three and one-half miles deep, using as a base a line drawn between Colon and Point Toro lights. The deepest sounding on this line is thirty-three feet, and the shape of the bed of the bay may be likened to a coal-shovel. The 7½-fathom curve runs 9,000 feet outside the base. In the season of north winds heavy swells roll in.

DANGERS TO NAVIGATION.

A group of submerged rocks lies seaward, and about 6,000 feet north of the Colon light-house. It carries but 22½ feet. This danger to navigation should ultimately be more suitably marked.

The following are the official instructions issued to mariners:

> ANCHORAGE.—"The best anchorage in ordinary weather is abreast the Pacific Mail Company's dock, about 600 yards off, but in bad weather it is better to anchor on the opposite side to avoid the heavy sea that rolls in around Toro Point; the holding ground is good, but there are many anchors and cables strewn about the bottom."
>
> NORTHERS.—"These winds occur in November, December, and January; they are seldom violent, but a heavy sea rolls in."
>
> "At Colon a norther is not necessarily a gale of wind. In fact, the wind frequently does not blow home, and is at times quite light; but very heavy ground swells heave into the bay. When the wind does blow home, as happened during the norther of December 19-21, 1890, no vessel can remain at anchor with safety.

> There is no way of predicting these dangerous northers. The barometer gives no indication; the 'fitful showers of rain in large drops' may or may not be an indication. The gradually increasing swell, supposed to be a forerunner of a norther, frequently proves to mean nothing.
>
> "The norther of December 19-21, 1890, was preceded on the 18th by a heavy swell and threatening weather, but toward evening the swell decreased, the weather cleared, and it looked like a fine night. Later in the night the swell commenced to heave in with greater force, so that steamers were compelled to leave their wharves. It was not till after daylight on the 19th that the full force of the norther began to be felt, and in a very short time it became so rough that all steamers put to sea. The Pacific Mail steamer Newport cut her lines and steamed across the bay to the anchorage under the lee of Toro Point, but was soon compelled to abandon this anchorage and put to sea. One steamer, lying in the harbor with two anchors down, dragged nearly one mile before she could get sufficient steam to be able to slip and go to sea.
>
> "During the season of northers, steamers should keep steam up constantly and be ready to move at a moment's notice. This is the custom of steamers of all nations which touch at this port, regardless of the time they may remain. However long the weather may have been threatening, when the norther does break it comes suddenly and leaves no time for preparations. If compelled to get under way, the surest way is to slip the chain and steam out to sea. It would be almost impossible to get up anchor without damage to the ship at such times, and there is always a risk of hooking one of the old anchors and chains with which the bottom of the harbor is strewn."

The above conditions mean that vessels will not be safe off Colon, even behind, breakwaters.

CURRENTS AT ATLANTIC ENTRANCE.

When a "norther" blows it piles water up at high tide in the Bay of Limon six feet above mean sea-level. Naturally, the water will back up a sea-level cut, running rapidly beyond Culebra. Now should a flood-rain fall in the watershed of the Canal below Gamboa, coincidently with the usual swift recession of the sea, there will be induced in a sea-level canal, for perhaps thirty miles, torrential currents, dangerously erosive, and detrimental to navigation. Against such likely contingencies there is in the Sea-Level scheme no protection whatever. This phenomenon may be seen between Port Said and Lake Timsah in rainless, hurricane-free Egypt, where the writer has observed currents of 1.5 knots per hour due to on-shore winds. Only last spring the streets of Colon were under water owing to a "norther." The effect of this wind in any canal with a sea level stretch here will be to pile up the waters in the mouth and the channel entrance. When the winds subside there is an efflux velocity up to 2 knots per hour. When a storm coincides the currents may reach 4 or more knots per hour in the stretch of sea-level canal near the Atlantic entrance, and no system of breakwaters can obviate this.

MINDI MOUTH OF CHAGRES

The French engineers started the canal at the southern end of Manzanillo Island, and the entrance involved two reverse curves of a radius too short for the largest modern vessels. The Basin and Canal they excavated toward Mindi will prove useful during construction, but should not be left to add to the Canal curvature. At the mouth of Mindi Creek a rock cut 70′ deep was made which allows the Chagres to discharge here.

Along the projected line of the canal and approach through Limon Bay from the 7½-fathom contour the characteristic formation is mud and clay, overlying usually at a depth of fifty feet an indurated clay-rock, and is a water-tight formation. Little coral is met with. At Mindi Gap, *indurated clay-rock* is encountered about 3,000 feet from the bay-shore, in the slopes of Jaramillo Hill—This rock is similar in character to that found in the old lock sites at Bohio.

During the past sixteen years the Chagres has discharged considerable silt into Limon Bay through the Mindi mouth. These deposits have also filled up some thousands of feet of the French Canal from Mindi toward Colon.

This channel may be reopened at but small expense, affording a direct inner connection between the construction harbor of Colon-Cristobal and that at the Canal terminus.

TIDAL FACTORS AND SEA CONDITIONS.

Mean tidal variation at Colon	1.43 feet
Maximum tidal variation at Colon	2.07 feet
Minimum tidal variation at Colon	0.62 feet

It is to be remarked that the times of High and Low Tide do not correspond on both sides of the Isthmus, and that consequently the tidal régime on both sides must be taken into the reckoning when considering the conditions attaching to the making of Canal Projects. It may be high tide at Colon and half tide at Panama, and the Atlantic may be 11 or 12 feet higher than the Pacific. In case of a "norther" it may be 16 or 17 feet higher. Conversely, there may be times when the Pacific is 11 to 12 feet higher than the Atlantic.

Northers and prevailing winds at Colon will also drive the waters of the sea into a sea-level canal, greatly accelerating the velocity due to tidal propagation. The efflux and influx velocity due to northers will approximate 2½ knots per hour, and this figure may reach over 4 knots should a heavy rainfall coincide.

CHAGRES RIVER MOUTH.

(OFFICIAL DESCRIPTION.)

"The flat, rocky promontory which bounds the north side of the entrance to the Chagres River is about 400 yards in length east and west, and about 175 yards broad. On the north, west and south sides it rises almost perpendicularly from the sea to the height of 82 feet at the outer end, and to that of 100 feet at the inner part. The western part is occupied by the fortifications of San Lorenzo, now in ruins, immediately in the rear of which there is a level plateau, 300 feet in length, terminating at a little mound commanding the valleys on all sides, and the only road to the castle. The works are everywhere in a state of decay, and the buildings almost in ruins.

"The south side of the entrance to the river is formed by a dark, sandy beach, and from Arenas Point to the base of the promontory opposite the width is 225 yards. From the inner end of the promontory the shore turns suddenly to the southward, and abreast Arenas Point the river is only 100 yards wide.

"The bar has 11 feet of water in the dry season, but the depth changes according to the state of the river. The mouth of the river, outside the bar, is obstructed by the Laja reef, a rocky ledge about 50 yards in diameter, which breaks in heavy weather, and is nearly even with the surface of the sea. The best approach is northward of Laja reef in depths of 14 feet, over a breadth of about 70 yards; within the bar the water deepens to 17 to 20 feet abreast the town, which is 200 yards above the bar. Here is the anchorage for vessels that can enter. Small craft also lie alongside the bank of the river southward of the town, as the shore at the town is a rocky ledge.

"Reefs nearly awash, ¼ mile in extent, which also break during strong winds, lie from ⅓ to ½ mile westward of Arenas Point, with shallow water extending toward the Laja. The passage between, though with 14 feet of water, is narrow and not recommended."

CHAGRES.

"The town of Chagres is on the eastern shore, between the Castle and Cano rivulet, which enters the river abreast Arenas Point; the shore in front is skirted by a flat, rocky ledge, so that small craft find it more convenient to lie alongside the bank, just above the Cano. Since the completion of the Panama Railroad, Chagres has become simply a fishing hamlet, and retains no evidence whatever of its former size and importance; a few thatched huts, and a population of 200 souls comprise the whole."

FACTORS AT THE PACIFIC TERMINUS.

At the Pacific Terminus of the Panama Canal, the ruling physical factors are climate and winds, tides and currents, fresh-water discharge and the undersea contours.

CLIMATE AND WINDS.

Of particular significance are the following official statements taken from United States Hydrographic Office reports:

> "On board ship, Panama is the most healthy place on the coast of Central America; vessels of war have remained here many months at a time, their crews continuing in a healthy state."

Vessels lying off Perico and Naos Islands in the roads experience the benefit of perfect sewage and access of the winds. The conditions on the Islands themselves are nearly identical with those aboard ship.

> "The wet season begins in May and lasts till November. The rains gradually increase until the season is fairly established in June, and continue through July, August and September with strong southerly winds. In December the rains cease and the N. W. and N. N. W. winds begin. During the dry season, regular land and sea breezes blow. The sea breeze sets in about 10.30 A.M. from S. S. W. It generally increases in force until 3.30 P. M., when it gradually subsides and at sunset is followed by a calm."

TIDES.

A Panama Canal without locks is only theoretically possible. To regulate the currents produced by the 22.5 foot tidal variation of the Pacific and secure safe transit, the Canal would have to be made wedge shaped, expanding in width from the Atlantic to Panama, and necessitating excavation several times that of a sea level Canal with a tide lock.

As the dyke projected from Sosa to West Rio Grande Hill will effectually eliminate the present tidal prism of the lower Rio Grande, the following data relate only to the tidal observations recorded at Naos Island:

PANAMA

TIDES AT NAOS ISLAND
FROM U. S. HYDROGRAPHIC CHART.

High water at full and change of moon	III h. 16 m.	
Low water at full and change of moon	IX h. 34 m.	
Corrected establishment for high water	III h. 02 m.	
Corrected establishment for low water	IX h. 12 m.	
Mean height of H. W., spring tides, above plane of reference	14.90	ft.
Mean height of L. W., spring tides, below plane of reference	2.08	"
Mean height of H. W., neap tides	10.35	"
Mean height of L. W., neap tides above plane	2.45	"
Mean range of all tides	12.85	"
Mean range of spring tides	16.98	"
Mean range of neap tides	7.80	"

The plane of reference is mean low water level.

Supplementing the above, there has been secured from the U. S. Coast and Geodetic Survey, Washington, the following tide records. These have been obtained by this Survey, from the French engineers of the Panama Canal. The data given on the official chart have been employed in the calculations relating to the Tidal Régime and Currents of the proposed new harbors.

HIGHEST AND LOWEST TIDES OBSERVED EACH MONTH DURING THE YEARS 1882, 1885, 1886, AND 1887.

MONTH	1882		1885		1886		1887	
	HIGHEST FT.	LOWEST FT.	HIGHEST FT.	LOWEST FT.	HIGHEST FT.	LOWEST FT.	HIGHEST FT.	LOWEST FT.
Jan	20.1	0.4	21.2	1.1	20.9	0.7	20.4	2.2
Feb	20.7	0.0	20.6	1.4	20.8	0.6	20.8	1.0
Mar	21.6	0.9	20.2	1.7	20.9	0.8	21.2	0.5
April	21.0	1.7	20.3	1.6	20.6	1.9	20.6	0.2
May	20.5	2.9	21.1	2.2	20.0	3.2	21.8	3.0
June	19.6	3.0	20.8	1.7	20.4	2.8	20.6	3.0
July	20.7	2.4	21.6	2.1	20.9	2.3	20.4	2.8
Aug.	22.2	1.8	21.5	2.1	21.8	1.8	22.0	2.8
Sept	22.0	0.9	21.6	2.5	21.9	2.0	22.5	1.8
Oct.	22.3	2.0	21.1	2.8	21.4	1.8	22.3	1.8
Nov.	21.2	2.9	21.1	2.8	20.4	2.1	21.8	2.0
Dec.	20.1	3.0	21.3	1.8	20.6	1.4	20.9	2.0

Mean of all high waters	18.26 ft.
Mean of all low waters	5.69 "
Mean range of all tides	12.57 "
Mean range of spring tides	15.93 "
Mean range of neap tides	8.72 "
Highest tide observed during 4 years	22.50 "
Lowest tide observed during 4 years	0.00 "
Extreme range of tide during 4 years	22.50 "

It appears from all records available that it is only rarely that the tide falls below — 9 below mean sea-level. Records show that it occurs 19 times a year and then for only half an hour or so, as per the following table:

TIDES AT PANAMA.

TIMES PER YEAR BELOW MEAN LOW WATER SPRINGS.

	—8	:	—9
January	7		0
February	9		2
March	7		4
April	8		3
May	7		2
June	4		0
July	4		0
August	10		0
September	11		4
October	12		2
November	7		2
December	3		0
	89		19
No. of Low Tides	730		730

Hence the writer concludes that — 9 feet below is a fair service datum to work from at the Panama end.

The above results are from observation made on Naos Island, Panama Harbor. We have about one month of tides at La Boca, which were observed by our Navy Department in 1900. The greatest observed range of tide during this month at La Boca was 21.00 feet and the mean range was about the same as at Naos Island.

It is to be remarked that the first and second tables do not agree, though it is stated that the French Canal engineers and the marine surveyors of the U. S. S. "Ranger" used the same datum plane, mean low water at the tide gauge station at the northeast end of Naos Island.

CURRENTS AND LITTORAL DRIFT.

The ocean currents are noted as being irregular, sometimes to the N. E. and sometimes to the S. W. They run from 1 to 1½ knots per hour, following the direction of the land and make a complete circuit of the Gulf and Bay of Panama.

TIDAL STREAMS.

The flood-tide stream sets to the N. W. and the ebb to the S. Their strength varies from ½ to 1½ knots per hour, the ebb being stronger than the flood. A long swell which occasionally sets into the Roads ceases with the flowing tide.

The following table is of interest because it shows a velocity of 2.2 knots (2.53 statute miles) per hour half-way up La Boca Channel—a condition adverse to navigation and ultimately requiring correction in any sea-level scheme, wherein the Rio Grande tidal prism is greatly increased instead of diminished.

TIDAL STREAMS IN PANAMA HARBOR AS OBSERVED BY THE U. S. S. "RANGER" IN FEBRUARY AND MARCH, 1900.

STATION	HALF FLOOD			HALF EBB		
	Range of tide in feet.	Set	Drift in knots per hour.	Range of tide in feet.	Set	Drift in knots per hour.
Eastward of Perico and Flamenco Islands....	21	N.W. ½ N.	0.6	20	S.E. by S.	0.6
Knocker Buoy	17	N.W.	0.5	16	S. by E.	0.6
Entrance to La Boca Channel............	17	W. by N.	0.4	21	S. by E.	0.7
Halfway up La Boca Channel............	17	W.N.W.	1.0	21	S.E. by E. ½ E.	**2.2**
La Boca Basin half-way between pier and inner channel buoys..	17	W. by N.	1.0	20	S.E. ½ E.	1.5

These currents and local streams, combined with wave motion, account for the littoral drift of sand and mud along the coast and their deposit in excavated channels, in Panama Bay, unprotected by breakwaters.

BED AND SHORE OF PANAMA BAY.

Sand, clay, mud, coral, volcanic tufa, and trap rock are the characteristic formations found in the bed and shores of Panama Bay. The Rio Grande has been a silt-bearing stream, and mud, coral, and sand, and several varieties of clay will be met with in under-water works. Ancon, Sosa, and other hills are of volcanic origin, and exist because their rock and indurated clay have resisted the weathering of the ages.

CONTOURS OF BED.

Attention is especially directed to the location of the 6, 7 and 8-fathom contours (36, 42 and 48 feet below mean low water). Having regard to the 1,000-foot ship of the early future, to wave motion, to the scend of the ship, and to the necessity for entering Panama's Harbor with a fully-laden vessel at the mean of the lowest low waters the 7½-fathom (45 feet) line must be accepted as the shallowest ruling contour. It will be noted that a submerged trough trends southeast of a point midway between Naos and Perico Island, that another heads north of Naos Island, trends westward and then southward, and that a third channel begins at the north end of Perico Island, and takes a course a little south of east. The latter is the approach to which the French and all Commission plans aimed, failing to realize the sizes that modern liners would attain.

It will become clear upon study that the shortest and most direct deep-water approach to a deep-water harbor at Panama lies along the axis of the first sea trough mentioned, which is between the other two. The trough now ends on the south side of the sandy isthmus, which joins Naos and Perico Islands at low tide. Doubtless clay or rock forms the backbone of this isthmus. The location planned by the Commission of 1901 ends, by a curious mistake, in a 45-foot hole, not at the 45-foot contour which is on that course a mile and a half further seaward. A schedule of the newly recognized results of contour data is as follows:

From La Boca Pier to the 7½-fathom contour the distances are as follows:

Route	I	via East Trough,	33,440 ft.	5½	sea miles.
"	II	" Central "	24,320 "	4	" "
"	III	" West "	30,400 "	5	" "
"	IV	West to Central	25,840 "	4¼	" "

From a reception buoy below a lock site between Sosa and Ancon Hill the distances run out as follows:

Route	V	East Trough	30,400 ft.	5	sea miles.
"	VI	Central "	21,280 "	3½	" "
"	VII	West "	30,400 "	5	" "
"	VIII	West to Central	24,320 "	4	" "

From Panama Haven, east of Ancon via East Trough, the distance is 28,800 feet, 4¾ sea miles.

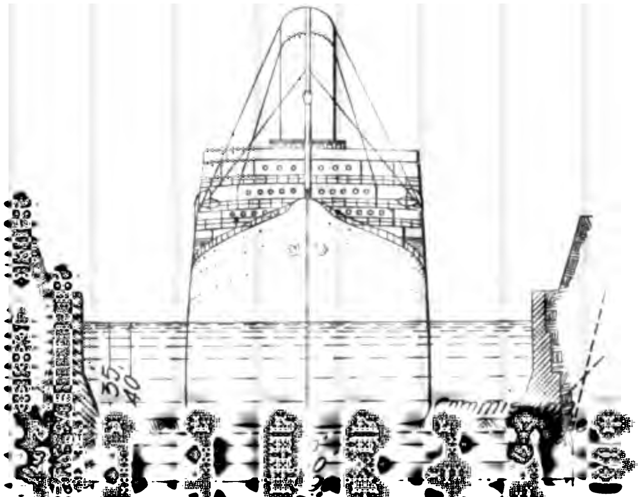
CONDITIONS OF NAVIGATION.

The conditions of navigation in Panama Bay and Roads are favorable. The islands and the hills on the mainland furnish conspicuous sites for lighthouses, for range beacons and leading lights. The Roads are shallow, and some dredging will be necessary to secure suitable harbor room. If the dredged areas are left exposed to littoral drift and deposits there will be constant shoaling.

CHAPTER III.

CONSTANTS.

[illegible] ation of any plan for the canal there must be established [illegible] are constant in the engineering equation. Of these pre- [illegible], the ruling dimensions of channel and locks are first. [illegible] head on the two kinds of structures that determine levels [illegible] locks in relation to their lifts and on the level determining [illegible]



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The Suez Canal at its completion was supposed to have anticipated the need of centuries. Its sanguine eulogists anked it among the enduring, finished products of that land of monuments. Yet, after a lapse of only thirty years its dimensions have proved so inadequate that the larger ships have ceased to essay it and are reaching Australia by the old weary route around the Cape. Within the years that have elapsed since the older Panama projects were mooted, the growth of vessels both for trade and for war has outstripped the most liberal estimates of coming sizes.

The United States has undertaken to construct an Isthmian Canal. It has provided by formal enactment that this waterway shall serve the ships of war and peace in their future as well as their immediate development. It is therefore fundamental and necessary to resolve the question of the present size and draft of vessels and deduce what will be their increase in the immediate future.

The average vessel engaged in ocean trade is the first type to be considered. As a generalization, its class limit is now about 3,300 tons. This is the average net registered tonnage of the vessels now using Suez, though it represents merely a theoretical point, since the tonnage average has been steadily advancing. Reduced to a classification, this average is made up of ocean-going freighters, the swarm of tramps and the drudges of the ocean whose usual length is from 200 to 400 feet; of liners, whose average is less than 600 feet long; of large liners which run now nearly to 800 feet. The importance which this latter class has attained is the predominate note of modern vessel building. The 661 foot Deutschland in 1900 was the marvel of its time. To-day there are under construction vessels 127 feet longer. The Kaiser Wilhelm der Zweite, launched two years later, was 684.3 feet in length. The Baltic, 708 feet 3 inches, followed in 1903, and with the assurance of the United States Government that a 40-foot clear channel would be afforded to New York, the Cunard Line has laid down two vessels 788 feet long of 88 feet beam. The whole tendency of merchant shipping is so manifestly toward greater size in all features that to lay a finger on a present ship is of small service in establishing the dimension of a canal to serve the needs of even the immediate future. Nevertheless, the following list of vessels is given to crystallize into definite figures the modern large vessel dimensions in the merchant service.

DIMENSIONS OF MERCHANT VESSELS.

YEAR		LENGTH		BREADTH		DEPTH		DRAFT	TONNAGE
		FT.	IN.	FT.	IN.	FT.	IN.	FT.	
1879	Gallia	430		44	6	34	4	23	4,891
1881	Servia	515		52	1	37		24	7,392
1883	Aurania	470		57	2	37	2	25	7,526
1884	Umbria	501	6	57	2	38	2	25	8,120
1888	New York	517		63	6	42		27	10,798
1889	Majestic	566		57	8	42	16	27	10,147
1893	Campania	601		65	2	41	10	28	12,950
1895	St. Louis	536		63		42		27	11,629
1897	Kaiser Wilhelm der Grosse	627		66		39		28	14,349
1900	Deutschland	661		67	3	40	3	34	16,502
1901	Celtic	681		75	3	44	1	36	20,904
1902	Cedric	681		75	3	44	1	36	21,035
1902	Kaiser Wilhelm II	684	3	72	3	40	2	34	19,361
1903	Minnesota	608		73	5	41	5	33	21,000
1903	Baltic	708	3	75	5	49		36	23,876
1905	New Cunarders	788		88		60		36	......

But we are not alone concerned with that ever advancing period, the present. What will be the vessels of the coming time? One way of attaining some idea is to find the rate of advance over a fair interval and apply it conservatively to the future. By the preceding table of longest typical ships of the year the growth from 1879 to 1905 has been from 430 feet to 788 feet, or at the rate of 13.8 feet per annum. In 15 years at this rate of advance, we would see the 1,000-foot ship.

Another way of deducing is to calculate the influence of the margin of profit. Professor J. H. Biles made, a few years ago, such an investigation in a paper read before the British Institution of Naval Architects. His estimates of carrying cost as related to dimensions were made on the basis of vessel lengths of 500 to 700 feet and draught from 27 feet 6 inches to 38 feet 6 inches. Comparing the cost of carrying a ton of cargo 5,000 miles at 12 knots, he arrived at the following unit figures:

Length of ship-feet	500	550	600	650	700
First series; draft, 27 ft. 6 in. over all. Cost per cargo ton	$2.10	$2.20	$2.34	$2.54	$2.73
Second series, draft varying: Draft	27′ 6	30′ 3	33′ 0	35′ 9	38′ 6
Cost per cargo ton	$2.10	$1.95	$1.85	$1.76	$1.71

It is seen from this table that while length in itself is not a source of cheaper unit transporation costs, increase in the other dimensions, notably draft, as corollary to it does reduce them. The same facts were noted by our own Deep Waterways Board of 1900 for the Great Lakes trade. It is an unavoidable conclusion that the end of ship growth is not yet. We may expect to see even within a decade steamers 1,000 feet long and 100 feet beam, drawing 38 feet of water, and it is for these vessels, by which the business of America and of the world in the Pacific can best be done, that the American Canal must provide.

The critical dimension of a battleship is the beam. This is increased to counterbalance the lesser length, cut below that of merchant vessels for convenience in maneuvering.

War vessels present a different aspect of the same tendencies. But there may accurately be said to be no present type or size. The following table brings the development up to the present year.

BRITISH BATTLESHIPS

FROM LORD BRASSEY'S MANUAL.

DATE OF COMPLETION	NAME	DISPLACEMENT	LENGTH		BEAM		DRAFT	
			FT.	IN.	FT.	IN.	FT.	IN.
1861	Warrior	9,210	380	2	58	4	6	9
1862	Black Prince	9,210	380	2	58	4	26	10
1864	Achilles	9,820	380		58	3½	27	3
1865	Valiant	6,710	280	2	56	4	26	8
1866	Bellerophon	7,550	300		56	1	26	7
1867	Minotaur	10,690	400		59	4¾	27	3
1868	Northumberland	10,780	400	4	59	5	27	1
1869	Monarch	8,320	330		57	6	26	7
1870	Invincible	6,010	280		54		23	2
1871	Sultan	9,290	225		59½		27	6
1872	Swiftsure	6,910	280		55		26	
1873	Devastation	9,330	285		62	3	27	6
1874	Rupert	5,440	250		53		23	7
1875	Dreadnought	10,820	320		63	10	26	9
1877	Alexandra	9,490	325		63	8	26	6
1878	Neptune	9,310	300		63		26	1
1880	Superb	9,170	332	3	59		26	5
1881	Inflexible	11,880	320		75		26	4
1882	Conqueror	6,200	270		58		24	
1883	Agamemnon	8,660	280		66		24	
1886	Collinwood	9,500	325		68		26	10
1888	Benbow	10,600	330		68	6	28	4
1889	Anson	10,600	330		68	6	27	3
1890	Nile	11,940	345		73		27	6
1892	Royal Sovereign	14,150	380		75		27	6
1894	Barfleur	10,500	360		70		25	6
1895	Majestic	14,900	390		75		27	6
1900	Ocean	12,950	390		74		25	6
1901	Formidable	15,000	400		75		26	9
1903	Duncan	14,000	405		75	6	26	6
1904	London	15,000	400		75		26	9
1904	Queen	15,000	400		75		26	9
1905	King Edward	16,350	425		78		26	9
Under Way	Lord Nelson	16,500						

BRITISH CRUISERS

FROM LORD BRASSEY'S MANUAL.

DATE OF LAUNCH.	NAME.	DISPLACEMENT	LENGTH		BEAM		DRAFT	
			FT.	IN.	FT.	IN.	FT.	IN.
1867	Juno	2,240	200		40	4	18	6
1868	Inconstant	5,780	337	4	50	3	25	6
1869	Active	3,080	270		42		21	4
1870	Tenedos	1,760	212		36		16	10
1871	Thetis	1,860	220		36		17	6
1873	Shah	6,250	334		52		26	5½
1874	Rover	3,460	280		43	6	23	
1875	Boadicea	4,140	280		45		23	8
1876	Bacchante	4,130	280		45	6	23	9
1877	Euralyus	4,140	280		45		23	3
1878	Mercury	3,730	300		46		22	
1880	Constace	2,380	225		44	6	19	2
1882	Arethusa	4,300	300		46		20	6
1884	Calliope	2,770	235		44	6	19	11
1885	Mersey	4,050	300		46		20	
1886	Forth	4,050	300		46		20	
1888	Magicienne	2,950	265		42		17	6
1889	Blake	9,000	375		65		25	9
1890	Edgar	7,350	360		60		23	9
1893	Cambrian	4,360	320		49	6	19	
1894	Eclipse	5,600	350		53		20	3
1895	Powerful	14,200	500		71		29	
1896	Arrogant	5,750	320		57	6	21	
1897	Diadem	11,000	435		69		26	
1899	Cressy	12,000	440		69	6	26	3
1900	Kent	9,800	440		66		24	6
1901	Drake	14,100	500		71		26	
1903	Antrim	10,700	450		68	6	25	
1904	Duke of Edinburgh	13,500	480		73	6	27	6
Bldg.	Warrior	13,500	480		73	6	27	6
Dsgn.	Minotaur	14,600						

Not only is the general tendency toward enlarging war vessel dimensions to be reckoned with as a future determinant, but also the new principles lately developed. One lesson above all has been taught by the Russian-Japanese war—the imperative need of housing guns by pairs in turrets and doing away with large open spaces in which the bursting of a single shell may annihilate half the crew. This only recently appreciated principle has caused the redesigning of some new United States war vessels. It carries with it the necessity for even larger and wider battleships. Flotation must then be furnished for heavier armor and for the row of turrets disposed along the sides and fore and aft. Growth is exemplified by the new United States battleships, now under construction, the "Vermont," the "Connecticut," "Kansas," and "Minnesota," for instance, displacing 16,000 tons, or at full load 17,650 tons, 450 feet long and 76 feet 10 inches beam, and the armored cruisers "Tennessee" and "Washington" of 14,500 tons displacement, 502 feet length, 72 feet 10½ inches breadth, 27 feet maximum draft. We are within sight of a battleship of 100 feet beam and over 20,000 tons displacement.

It is for the vessels of this size and those to follow that the canal must be planned. The newest and the best must be able to pass safely through the American waterway. The great liners that connect Europe with America must be the standard, not the ocean tramps; the largest and most powerful war vessels, not those already made obsolete by the lessons of the Battle in the Sea of Japan.

DEPTH.

We have, then, to translate these vessel dimensions into terms of canal prism. The first factor is that of depth.

In 1901, preparing for the Government of South Australia a Project for the Harbor at Port Adelaide, which is now nearly completed, the writer reported as follows:

> "Prior to the coming of the White Star boats, the largest steamers visiting the Port were those of the regular lines, via the Suez Canal, where at present the permitted draft is 25 feet 8 inches. This waterway must, however, presently be systematically widened and deepened and then the Australian Mail steamers must increase in size. The intention to permit an added draft of half a meter has within the last sixty days been officially bulletined. With the development of South Africa and the realization on the part of ship owners in Europe that it is more profitable to operate large ships than small ones, an advanced type of vessel has appeared as evidenced by the White Star steamers mentioned (now five in number), regularly using the route around the Cape of Good Hope. It is noticeable also that the new ships now being built for the Trans-ocean trade in the United Kingdom and the United States have nearly double the carrying capacity of these Australian White Star steamers. The Plimsoll marks in the latter ships allow a draft of 32 feet 6 inches."

The allowed draft of the newest Trans-Atlantic liners approximates 38 feet. That they are not loaded to this depth is an affair of harbor improvement wherein advance has not latterly kept pace with vessel growth. But if the great harbors lag behind vessel demands it is no reason why a great canal should do so, since economy of transit should be a nation's economic care.

As a large vessel draws nearly a foot more in fresh water than in salt and a lock canal will contain fresh water; as further there are sure to be minor inequalities of the bottom and as vessels under way have a tendency to trim by the stern, it is safe to say that even given a normal 40-foot channel, the draft permitted to transit vessels will not be more than 37 feet, or 36 feet sea-draft, and such an excess of depth over draft is prudent and necessary. There is no reason why such a vessel should not be a most desirable size to operate, say, between Seattle and New York or Liverpool, when the canal is completed. The harbors are now deep enough for a service of this character. The recent report recommending a Canal channel but 35 feet deep cannot be justified. This is entirely inadequate. A 40-foot canal should be taken as the standard of construction. And so near are the present ships to this limit that the canal plan should ideally have, as an inherent potentiality, the ability to secure at nominal expense a 45-foot channel against the time when that depth will become necessary to meet the fullest demands of commerce.

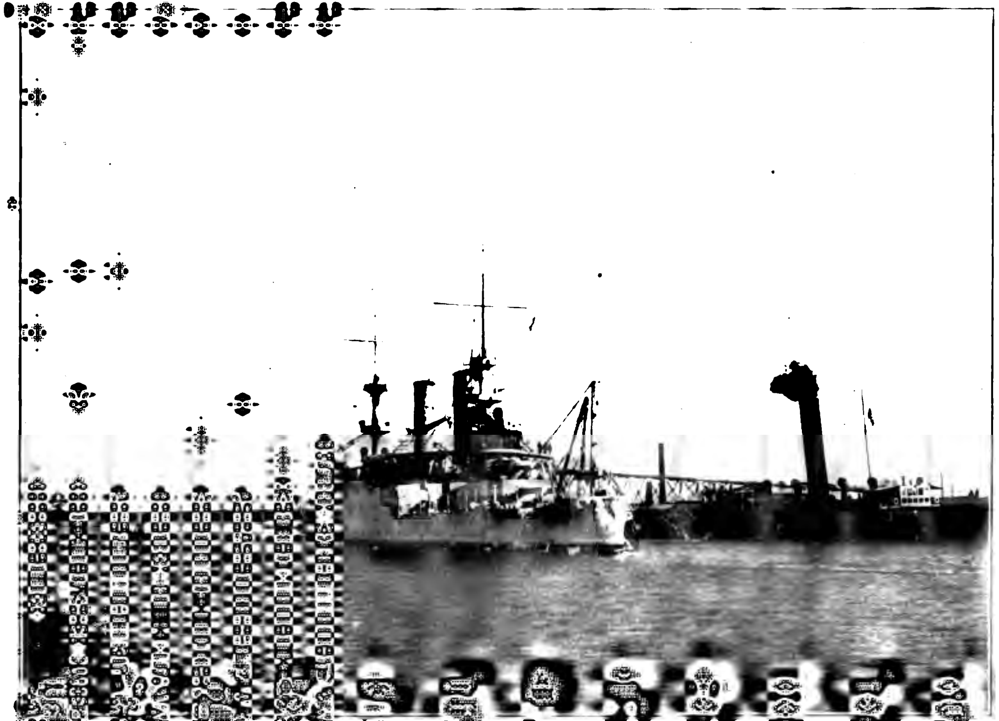
Not only is this figure the one arrived at by dispassionate analysis of conditions, regardless of what may be its effect on the canal plan and looking only for the best, but it is also the figure taken as a standard for all the newest of the great harbor works of the world. The approach to Liverpool has recently been established at 40 feet. The new Ambrose channel in New York will be dredged to that plane. The recognition of this depth as the standard is embodied in the recent Belgian law for improving the port of Antwerp so as to make it the greatest harbor in Europe. It includes the changing of the River Schelt by means of the "Grande Coupure" which incorporates the writer's alignment and project accepted by the Ministry in 1895. This national work involves the displacement of more than half as much material as does the Panama Canal.

WIDTH AND SLOPE.

It is not enough that this costly waterway shall admit the passage of ships simply; is must make practical their *safe* transit. The cross-section, therefore, of the passage to be traversed becomes of vital and primary importance, entirely aside from problems of the necessary depth, since this is the ruling factor of safe steering.

What is the minimum cross-section which will enable the largest merchant or naval vessels of, say, forty years hence to traverse in security the narrow straight reaches or to negotiate the curves of the canal at a safe steering speed and what is that speed? No first real effort has been made anywhere to determine these fundamental questions in their relation to the largest vessels of even the present time. The surface and bottom widths, and the bank slopes are matters of vital import for which a standard should be established. Since a year and a half has passed and the scientific investigation imperative to reaching a safe conclusion as to dimensions has not even been started, there may with profit be given some pertinent facts bearing upon the question and some personal conclusions.

[illegible] el from which to draw deductions for Panama is the [illegible] f the floor, originally 72 feet, was some several years [illegible] to 118 feet. The width of the canal at the surface [illegible] greater part of its length is about 320 feet; where the [illegible] ; where the banks are low the breadth expands to 330 [illegible] the nighborhood of El Guisr, Serapeum, and Chalouf [illegible], and 4 miles in length.



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displacement. The large liners and most modern battleships suffer, however, a very great inconvenience. The "Grosser Kurfurst," 560 feet 6 inches long by 62 feet 3 inches beam, by 35 feet 9 inches depth, in passing struck several times on either bank, and steering was accomplished only with the greatest difficulty.

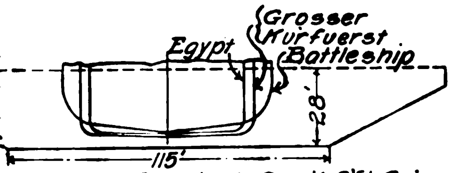
While the dredge "Hercules," designed by the author for the Queensland Government, was undergoing capacity tests in the Suez Canal, the U. S. battleship "Kentucky" passed through, giving an excellent opportunity for first-hand observation. The battleship had to be towed at the end of a long hawser, owing to the impossibility of steering when using her own engines. When her engines were stopped or just turning, she could be kept in mid-channel in the narrow sections of the canal, and towed at from 1½ to 2 miles an hour, but when in these parts of the canal she was towed faster, 3½ to 4 knots, or when she attempted to use her own steam, she slewed to one side and the other, making a quick dive for the canal banks, and once started the combined forces of her twin screws and rudder, working in a contrary direction, had no apparent effect in stopping her. In the wider parts of the canal a fair speed could be reached and her engines used.

The same difficulties were experienced by a large British battleship towed by a tug, which partially obviate them by trailing 60 fathoms of chain behind to hold her stern in the centre of the canal.

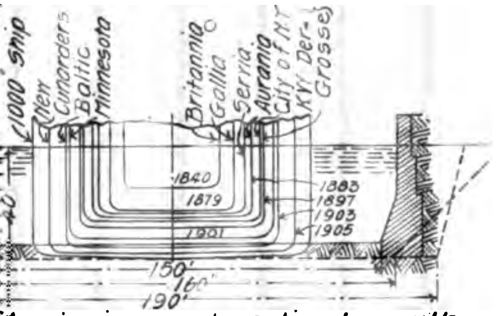
This poor steering is due to currents induced by the moving ship, to its speed and to the area of the midship-section and the ship displacement as related to the canal section. It apparently is not due to the action of the screws astern or the tug would be able to tow the ship at the desired speed. It is found that a constricted channel permits a swifter flow on one side as the ship approaches the bank. An analysis by parallelogram of forces discloses that the resultant representing the force setting the bow toward the bank increases rapidly as the center line is departed from and the ship quickly becomes uncontrollable by screw or rudder.

To illustrate this relation in the above case, a characteristic section of the narrow reach at Seuil del Guisr on the Suez Canal is compared with the U. S. Battleship "Kentucky." The effective dimensions of the vessel were 368 x 72 feet 2½ inches x 23 feet 8 inches, and displacement 11,540 tons. The canal cross-section has a bottom width of 115 feet, top width of 233 feet and a depth of 29 feet 6 inches.

At speeds of three to five knots per hour it is safe to say with ships of this size that there is a negligible amount of water passing sternward beneath the boat to fill the displaced volume of the moving ship. The sections which are [illegible] passing of this water sternward are those between [illegible] sides of the ship and extending down to the turn of [illegible] velocity of such water would be reached abreast of the [illegible] ship, since at such points the distances from the canal [illegible] forecasting the probable behavior of ships in a canal [illegible] consider more factors than these, since the forces [illegible] such conditions uncontrollable are in addition depend- [illegible], model, coefficient, the current, etc. At the same [illegible] model, coefficient and current the smallest canal prisms [illegible] tion would be proportional, in certain limits, to a co-



[illegible] of Suez Canal at Seuil D'El-Guisr



[illegible] showing immersed sectional growth [illegible] ships from 1840 to 1905 and section [illegible] Culebra cut. - Commission Project.

[illegible]

report of the Engineering Committee of the last commission the following language is used:

> "The advantages of a sea-level canal across the Isthmus are most obvious. It would be a waterway with no restriction to navigation, and which could be easily enlarged by widening or deepening at any time in the future, to accommodate an increased traffic, without any inconvenience to the shipping using it, whereas a lock canal is in reality a permanent restriction to the volume of traffic and size of ships that use it."

To such premises the writer does not subscribe. A long, narrow waterway having a section of only 7,150 square feet in "firm earth," and far less in the Culebra division, cannot be either so safely or so quickly traversed by large vessels as a canal with lake navigation and locks. One of the fundamental objections to a sea-level canal at Panama is the very fact that such a channel must be fatally narrow unless the quantities excavated are to be too appalling to contemplate under the attendant circumstances.

The wider the section at the water surface the better can ships be controlled. It follows that the longer lake navigation of the canal can be made, the safer it will be for shipping. A lock canal with sufficient lake navigation, if the locks be suited to taking 1,000-foot vessels, is not "a permanent restriction to the volume of traffic." More ships can be put through and at an average higher rate of speed than in the sea-level channel, whose dimensions are permanently confined and fixed from the outset by the tremendous cost of further enlargement and the inevitable annual deficits which the outlay entails.

Such a sea-level channel cannot "be easily widened and deepened without any inconvenience to the shipping using it." To deepen such a canal the five feet necessary to accommodate the largest vessels of to-day involves the excavation of vast quantities from the bottom and slopes in which the spoil must be mostly moved long distances longitudinally. Bottom and lower side slope work give, as is later shown, the highest unit of cost. And, further, it necessitates the excavation of rock under water rather than in the dry, as would be done were the proper channel made at first. In the present state of the art, submerged rock excavation costs four to *eight times* as much as dry.

Having regard for all factors it is believed to be a safe assumption that the bottom width should be at least 150 feet and the underwater slope should rarely be steeper than 2.5 to 1. This is not because of the geological formation, but because to steer safely the water divided and displaced by a steadily advancing vessel must readily reach the void astern. In certain soft underwater strata this slope of course may best be 3 or 4 to 1 or even flatter. Surface width is prerequisite for safe steering. The above factors give a water surface width of 350 feet. These dimensions mean a minimum water section of 10,000 square feet in tangents. If one takes the steepest slope in the Suez 2 to 1 at El-Guisr, he has 8000 square feet as an irreducible minimum at the narrowest point in the canal.

The great depth of the Culebra Section makes terracing neccessary and the only recourse is to select a form of section demanded by vessels and rates of slope under and above water which will be permanent, and then make the sides proof against erosive currents induced in the transit of large ships.

The minimum sectional area should be not less than 8,000 sq. ft. If then a batter of 1 in 4 is given to the walls, there will have to be a channel bottom width of 190 feet, and a surface width of 210 feet. With such a shape of section, fenders along the sides will certainly be advisable to prevent the enormous sheering blows which a great vessel is liable to strike at any moment that her bow gets to one side of the canal's axis and upsets the equilibrium of forces. If the bottom width is 160 feet and the underwater slopes 1 to 1, we have a surface width of 240 feet which, while far from ideal, is much fitter to negotiate, although it means 15 ft. more slicing along the imposing terraces above water. The best navigable dimensions of this cut approximate probably the latter figures having regard to the vast increase of excavation which greater width at water surface involves.

Slopes above water will naturally be determined by the formation, taking account of stability and weathering. The slopes of the Culebra Section above water will vary from 1¼ to 2 to 1 according to the ground, and must be properly terraced, tunneled, and drained.

A most important precaution is to secure low, wide, spoilbanks instead of high, narrow ones. The crestline of a ship canal spoilbank should be always kept low, otherwise the expense of removing silt deposits, and of maintaining or deepening the cross-section will be greatly enhanced. It is best, where practicable, to avoid making spoilbanks on the Isthmus, adjacent to the canal.

With the demand for enlargement pressing hard upon the dividends, the French regret now the short-sighted imminence of the spoilbanks and their high crest line at Suez.

CURRENTS.

There are many lessons to be learned from the intimate knowledge of working conditions in a great canal like the latter. One of the most important is that the berms on either side should be very wide. It has to come to pass at Suez that now no berm is left on either bank—and every underwater slope has been flattened by erosion and the operations of maintenance so that 1½ to 1 and 2 to 1 slopes have become from 2½ to 4 to 1. The most difficult part of the Suez Canal passage, leaving the effect of a strong wind out of consideration, is between Suez and the Little Bitter Lake, on account of the rapid tides that prevail in that space; and it has been recommended with good reason that this portion should be navigated either during the slack or against an opposing tide. Ships have frequently grounded in the locality, probably from disregard of this precaution. The swift currents and eddies which invariably accompany the passage of a large vessel at a speed of only 3 or 4 knots per hour, continually undermine even firm earth.

In the tidal part of the Suez Canal, between Chalouf and Port Tewfik, spring tides run at the rate of 2½ knots an hour, and occasionally much stronger. Their strength increases from Chalouf to near Madama, where they are strongest. In passing the mouth of Suez creek, allowance must be made by pilots for the strong tidal stream setting across the canal, frequently in the contrary direction to the stream in the channel.

By starting from the Red Sea entrance an hour before low water, a vessel will arrive in the Bitter Lakes before the flood-tide overtakes her, and will have had slack water nearly all the way, and it is generally recommended that the tidal part of the canal should be navigated either at slack water or against the tide. Vessels proceeding through with a swift flowing stream must guard particularly against hitting on either side; for if the bow touches, they are liable to be swung across the channel and block the canal until the stream turns.

It may be seen from this how vitally the efficiency of an interoceanic canal may be reduced by undue currents. As the canon in this regard it is assured that the basis of speed in the most restricted channel tangents should be set at no more than 5 knots per hour. In open lake navigation this will be of course increased greatly. A current of 6 feet per second (3.5 knots per hour) will not appreciably injure canal banks. Navigation is not inconvenienced by a velocity of one meter or conservatively, say, 3 feet per second, provided that there is an adequate waterway section. A good canal should at no period have currents beyond this rate.

A "LOCKLESS CANAL."

The next primary constant deals with locks. Every project contemplates at least one of these structures, and one alone if it be too small, is by so much a fetter upon commerce.

It may be of use to explain this as there has been some discussion, even officially, of a lockless channel. The length of the Panama Canal is the distance from La Boca to Limon Bay. To this, however, must be added what may flow from the Atlantic toward Panama at the last half of the Pacific ebb tide, which answers to increased length or size of tidal prism. The alignment location of the canal is definitely fixed by topography and adoption. The factor of length is, therefore, within limits unalterable. The depth is regulated by a plane at such a bottom grade as will pass ships drawing, say, 36 feet at low water. Deepening is the costliest process because it involves bottom and side excavations; therefore, depth can be considered fixed at the highest plane which will serve commercial needs. Grade for governing the velocity of the efflux and influx in a lockless system can be changed therefore only by modifying the one remaining primary factor, width.

The difference of tides between the Atlantic and Pacific Oceans is 12 feet. When the norther is blowing and is driving the water back through the canal this difference may reach 15 or 16 feet. A lockless canal becomes in effect a river emerging from an exhaustless reservoir, the Atlantic, running some forty miles through an artificial channel and emptying into the Pacific at stages of tide below mean sea-level. At stages of flood tide above mean sea level, the current is reversed. Now these tides must be arranged for somehow. The factors of length, alignment and depth are all fixed and unalterable. The two remaining factors are grades and widths, the former determining the current velocities.

It is pertinent to analyze what is involved in a proposition to absorb the tides by adjusting the Canal width. Contemplate the cross section areas, the water grades and the velocities of a normal navigable lockless tidal river emptying into the Pacific. To secure a sufficiently uniform velocity in regulating an ordinary tidal river with a depth approximating the navigable plane, the *factor of width must expand by a certain ratio per unit of length*. According to the ratios employed, the current velocities may be varied, and one may set up violent erosion of the bottom and sides by too small a coefficient of expansion. The banks of a canal are, usually, substantially parallel. The section of the Suez between the Little Bitter Lake and Port Tewfik, dealing with a tide of one-third the range of Panama, has the limit of current 2½ knots admitted by parallel banks which extend for only 11 miles.

Expansion ratios vary with the local tidal factors and conditions.

For the exposition of the science of determining the proper ratio in a given case, the world is indebted to Oberbaurath Ludwig Franzius, whose monumental success on the Weser attests the genius which won an erratic river to a regular flow. Of several examples the Hoogli River, of which the author made a special study and report for the Calcutta Port Commission, has substantially the tidal régime and range which obtains at Naos Island in Panama Bay. It is enough to say that an inspection of official hydrographic charts will disclose there velocities of current, due to the tidal prism alone, from 3 to 5 times that which could be tolerated in the Panama Canal. The ratio on this river works out about 1 to 85, and this is a fair average of other rivers.

We may then, for purposes of illustration only, make a table showing the widths which a Panama Tidal River would have if the smaller ratio of expansion, 1 foot to 100 feet was employed.

PLACE.	DISTANCE, MILES.		WIDTH, WATER SURFACE, FEET.
Mindi			400
Bohio	13	400 + (13 × 52.8)	1086
Obispo	26	400 + (26 × 52.8)	1773
Culebra	32	400 + (32 × 52.8)	2089
La Boca	40	400 + (40 × 52.8)	2512

A Lockless Canal may be therefore dismissed.

LOCK DIMENSIONS

Hence to correspond with the channel dimensions the lock dimensions must be determined. Locks are directly dependent upon vessel size for their dimensions and consequently for their design of construction. From the conclusions reached in regard to future vessel and channel needs there follow certain necessary corcollaries. Forty feet was chosen as the channel standard. For a nominal 40 foot channel the minimum depth over the lock sill may be less—but as a future deepening of the canal is possible, forty feet is chosen likewise as the best lock depth.

The length which the prospective increase of vessels inexorably demands is one that renders the lock sufficient for a 1,000 foot ship. It is concluded, therefore, that locks no less than 1,050 feet long should be installed.

The width for the present gauge should meet the needs of such boats as the new Cunarders, of 88 feet beam, and for the future those which will be at least 100 feet wide. For these coming ships of 100 feet beam, 2′ 6″ clearance is small enough when such a mighty weight is moving into place. The least lock-gate width proper for the Panama Canal is 105 feet. The standard lock dimensions herein taken are therefore 1050′x105′x40′.

STRUCTURE.

It has been wisely agreed that twin locks shall be employed in every case. There remains, therefore, to be considered the best form The main distinction lies in the arrangement and type of gates. These may be advisedly adjusted with a view to the three sizes of ships which will be the canal carriers. It has been said that ships less than 450 feet long move the bulk of the ocean freight; that most liners are longer than 450 feet, but shorter than 600 feet. If a third gate be placed between the two ends of the lock, in such a position that one section can take all below 450 feet, and the other the 450′ to 575′ class of vessels, the best arranged lock system, will be furnished. The whole 1,050 foot lock should not have to be used for a small boat, but only the section nearest its size. In thisway there will be an economy in operation and in lockage water.

The mitering gate is accepted as the standard type. The science of its successful construction and operation is proven by experience. The length and depth of the gate if coupled with excessive lift, run up the pressures and make the design one of great massiveness, hence with incident difficulties of maneuvering. Mitering gates for the above depth and width may be planned with all the necessary factors of safety, cost and convenience for a lift up to 40 foot. In this system the gates and abutments are liable to damage practically only from earthquake, aside from deterioration, which is here minimized by fresh water at both ends of the lock. The writer favors considering the incorporation into the lock design of floating caisson gates as emergency provisions which may be used to facilitate repairs, or, in case of the disablement of a mitering gate, to perform its functions, temporarily.

ALLOWABLE HEADS ON STRUCTURES.

LOCK LIFTS.

One primary question to be settled before taking a decision regarding allowable lock lifts is whether or not it is desirable to employ lock flights of low lift units as a solution for the problem of heads. Some contend that if there is any perplexity about a 40 ft. lift lock, it is better to put in two of 20 feet, and so eliminate all doubt. The question should be met fairly and scientifically, and a definite standard of lock lift be laid down rather than have recourse to expedients.

Two locks each of 20 ft. lift, to take an example, must, as a general principle, cost so much more in money, in maintenance expense, and in trouble for vessels passing through, than one lock of 40 ft. lift, that the superiority of the latter, if found practicable under the circumstances, cannot be doubted. As affecting the time and speed for a large vessel, for instance, with a rate of lift after the lock has been entered of 2′ 6″ per minute, a vessel will spend from 10 to 20 minutes in the raising or lowering process in a lock of from 25 to 50 ft. lift. But in slowing down and passing in, opening and closing gates, the difference between a lock of 50 and two of 25 works out roughly 38 as against 57 minutes. In the proposed Lewiston Flight of six locks on the Great Lakes Deep Waterway Canal, it was calculated that with 40 ft. lifts the time of passing the flight was to be figured at 108 minutes, with 20 ft. lifts 186 minutes, subjecting each ship to 78 minutes minimum delay. The costs for this flight with 20 ft. lifts was figured at $4,600,000 more than for 40 ft. lifts.

Since a canal is primarily for navigation purposes, and each delay and difficulty given to shipping is a diminution to its utility, it is a fair conclusion that the right principle to work towards is "one lock to one level."

Such being the case, to have each lift as high as is legitimate is a desideratum. Recognizing this, it is best to determine permissible lifts in as unbiased a way as possible, and then discount the result on the side of conservatism. While a greater liberality in allowable heights may eventually be considered entirely safe, there will be no reason to go below the lifts and levels here given.

The first ruling factor is the foundation. It will be taken in the following discussion that solid foundations exist for all the proposed locks. Such is indeed the case. In each of the critical points whose geology has been outlined there is an available lock-site meeting the most rigid demands.

Engineering precedents are a next factor. The best discussion is that given in the Report by the Deep-Waterway Board of 1900. It was from the excellent studies of this Board that the lock-lifts and dimensions recommended by the Isthmian Canal Commission of 1901 were primarily derived. The locks which this latter body planned for Panama had lifts of 41 to 45 ft., with dimensions 740 ft.x84x35 ft. The New Poe lock on the St. Mary's Falls Canal is 800 ft long and 100 ft. wide, and its lift is 20 ft. A third method of determining the allowable heads is by mathematically figuring the pressures and factors for various heads on the gates of a lock 105 ft. wide and 40 ft. deep. The mathematics of lock gates were worked out with masterful precision in the Deep Waterways Report for gates to meet the needs of locks from 60 to 80 ft. wide, 21 to 30 ft. depth on sills and lifts from 10 to 50 ft. The results for the maximum of these was the determination that mitering gates were the type found most satisfying and that they could be designed with a suitable margin of safety for the dimensions named.

With a high head the strains run the structure to undue massiveness and difficulty of maneuvering. A narrow lock may have a higher lift, but when one goes to the maximum of width the lift should be proportionately reduced. A mitering gate may certainly be constructed with all the necessary factors of safety, cost and convenience for a lift of 40 feet. The figure herein taken to be conservative, fair and standard is set at 36 feet, the structure being planned to admit variations of level.

DAM HEADS.

The final constant is kindred to that of lock lifts, and concerns the allowable head of water on dam structures. It has been seen in the Summary of Factors and Conditions, that while in certain locations rock of such character as to serve as dam foundations does exist, in several of the other ruling locations it does not. The question to be decided then is what head of water may be taken as the allowable standard, under Isthmian conditions, for a dam without solid rock foundations.

To this question the best answer is precedent. An excellent instance is found in connection with the common dykes or levees. Such a barrier may be constructed of many materials, but for convenience, it is usually made of earth. For greater security it may be faced with rock or concrete, or be provided with a watertight core. Upon the alluvial soil of the Mississippi, Nile and Po, the sand and clay and peat and mud of Netherland bottoms, have been erected thousands of miles of such dykes, facing rivers and boisterous seas. On the foundations of soft material, earth, clay or conglomerate, upon almost anything in short, there exist sufficient examples of this structure, sustaining up to 40 ft. head to make this height of 40 feet a firm criterion.

The simple dyke structure may be elaborated into a rock and earth fill dam, provided with a watertight core. By tailing out such a structure to a great length, a high head of water can be sustained, but the size of the dam becomes too vast. It is physically possible and sufficiently facile to be worth considering in an engineering way, to plan an earth dam, on alluvial foundations for a head, up to 60 or 70 ft. It may be that such a construction may, by those less conservative, be deemed advisable. It is a matter of balancing the decrease of excavation so resulting against the cumulating cost of such a dam in time and money. The limitation here set, must be to a certain extent, arbitary. In comparing the profiles, it can be seen that a 60 ft. head dam requiring, to deal with percolation, a length along the valley of 1,410 ft., is a vast work and that its volume and difficulty of construction should be several times those of a 30′ head dam, on similar principles.

Therefore, as eminently safe and subject only to modification in a more liberal way and admitting variations of level, a 36′ full or net head is adopted as standard for dams here on alluvial foundations.

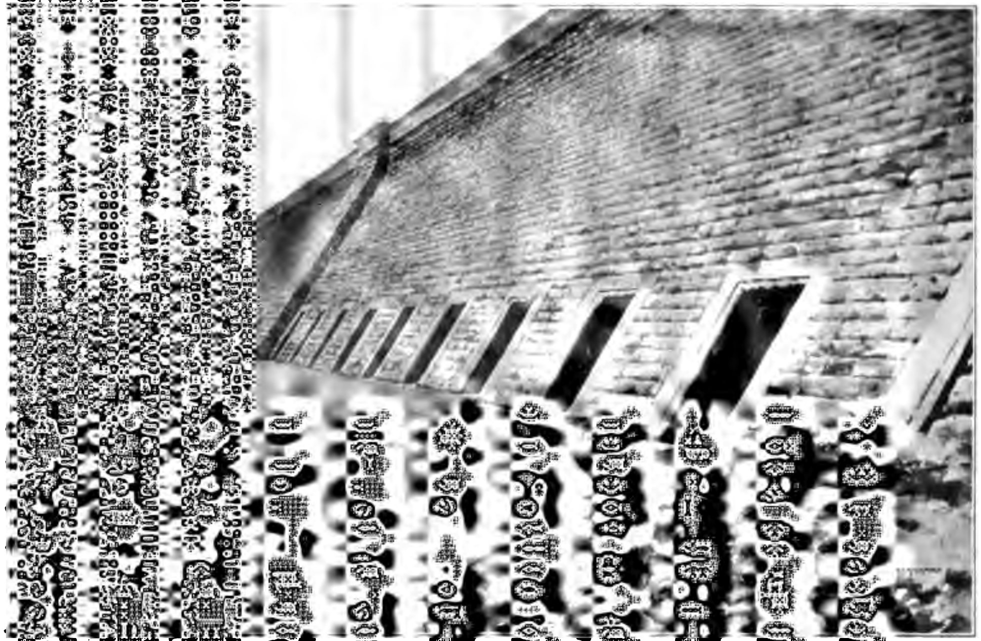
CHAPTER IV.

CONTROL SYSTEM

ELEMENTS.

[illegible] AND DIVIDED CHANNEL CONTROL. GAMBOA, ALHA-[illegible] CANO SLUICE DAMS, SILT. OBISPO DIVIDING [illegible]LE, EXPANDING CHANNELS, CURRENT EQUALIZATION.

[illegible] this method of Chagres Control the proposals of the author are,



[illegible]

[illegible] water [illegible] constructed [illegible] Gamboa [illegible]

2. That a similar dam be constructed at Alhajuela, and on the Rio Caño.

3. That the construction be such that on the upstream side of each dam a large silt trapping pond may be formed.

4. That at Obispo the Chagres be divided, half being sent to the Atlantic and half to the Pacific down the Canal.

5. That currents be equalized by an appropriate expanding section.

THE SLUICE DAMS.

The Chagres regulation measures are based upon what may be termed Empty Basin Control by means of under sluice dams. The writer is aware that all this is a system of river regulation entirely new in the world's experience, but there is nothing more radical or experimental in it than in reversing the motion of a steam engine. The possibility of both performances is inherent in both instruments. Under-sluice dams have not been put to such duty, because the occasion has not before arisen.

The Assuan Dam. The gifted designer of the Assuan Dam, Sir Wm. Willcocks, C.M.G. and M.I.C.E., thus described his monumental contribution to the science of irrigation:

> "The Assuan Dam is a work of a type which is new in the world. If successful, it will mark an epoch in dam building. There must be sites on the torrential rivers of the arid and semi-arid regions of South Africa, Australia and North America, where dams of the type of the one at Assuan will supply a want which has long been recognized. A reservoir dam, which will allow the early floods laden with deposits a free and unimpeded passage and which will afterward captivate the comparatively clear waters of the terminal inundations and early percolations and store them for subsequent use, ought to put new life into many abandoned projects for perennial irrigation. But the provision of perennial irrigation is not the only object for which this type of dam may be employed. Provided with its numerous flood openings, it may be looked upon as a weir capable of controlling the mightiest rivers in flood just as ordinary weirs control them in times of low supply; it may be thus utilized for the regulation of the flood supplies of rivers and for their employment in basins of inundation irrigation."

In projecting dams of this type at Cano, Alhajuela and Gamboa as well as at Mindi and Sosa Barrages, cognizance is taken of this inspiring mile-and-a-quarter wide demonstration that a continental river may be valved as a water-pipe, and may as perfectly perform its allotted task. The Assuan Dam, however, had as its function to impound a large volume of clear Nile water and to let it out gradually during the irrigation season, after allowing the early silt-bearing floods to pass.

The reversal of this duty is proposed by the author for the Panama sluice dams. What is here required is to catch and hold the high floods and by maneuvering the sluices let them run off gradually and harmlessly.

The proposed Panama dams are most nearly parallelled in several notable works in India as well as in this Egyptian monument.

	Head	Maximum height above foundations	Area Watershed sq. m.	Rainfall inches	Run-off C. F. S.
Bhatgur Dam....		130	128		50 to 50,000
Periar............	153	180	300		250 to 120,000
Poona Dam......		108	196	65″ to 200″	
Tansa Dam......		118	52½	150″ to 200″	
Assuan Dam....	81	135			7000 to 475,000

The foundations of the above works are on rock, but all are used for water storage simply, and the Assuan only affords a complete structural parallel to the type and design of regulation dam which is advocated for the Isthmus.

This projected system of river control then must be accepted as practicable, as it is simple. It remains to measure the two methods against existing conditions without prejudice or past partizanship and looking only toward the highest sense of engineering security and fitness.

All former projects have been chained to one mode of Chagres Control, the Solid Dam and Diversion System. The new proposal has a primary advantage from having realized the application of the second fundamental method which includes any combinations possible between the two. Its plan was evolved from a study of conditions with the opportunity to apply where best fitted, either the solid dam system or the empty basin and divided channel system or the combination—three alternatives where other projects had but one. The results of these studies are hereafter presented.

THE SLUICE DAMS.

At Gamboa, Alhajuela and Cano are the proposed masonry sluice dams of the Empty Basin System, the first two, of the Assuan type to control the Chagres, the third to control a fair-sized stream, the Rio Caño.

GAMBOA DAM.

Plane of Reference is Mean Sea-Level.

High water, 108.8 feet.
Ground, 45 feet.
Rock foundation, sea-level.

ALHAJUELA DAM.

High water, 170.5 feet.
Extreme low water of present river, 92.0 feet.
Rock foundation, 62.0 feet.
Back water from Gamboa, 108.8 feet.

Each of the Panama dams is to be provided with a very substantial down-stream-stepped apron, the better to assure the stability and permanence of the foundations and to eliminate any harmful cascade. Such an apron was originally omitted at Assuan, but prudence has recently provided this usual adjunct.

As at Assuan, the Stoney type and size of sluice gate, about 6′ x 23′ should be adopted. The sluices should be arranged so that they may be operated electrically, but they should likewise be controlled by other power in case the electric mechanism be out of service. By the following formula of discharge: $q=8.02\ c\ b\ d\ h$, $c=0.6$, $b=6$, $d=28$, the discharge of each Alhajuela sluice with reservoir full $=5{,}200$ c. f. s. and for each Gamboa sluice with reservoir full $=4{,}700$ c. f. s.

It is proposed to make a permanent large silt-pond above Gamboa by arranging that the bottom of the sluiceways be fixed at an elevation which will create a settling pool of the proper area and depth. In the trap thus provided, almost all the deposit contributed by the tributary water-shed will settle. It will be excavated by well-known methods, and be placed in self-unloading hopper barges which could take it to sea from Obispo Basin or could deposit it on low ground margining the Lakes.

DETAILS OF CONTROL.

The Gamboa Dam will control, regulate and discharge: the drainage of the Gamboa Basin Watershed, the regulated outflow from the Alhajuela Basin.

The Alhajuela Dam will control, regulate and discharge: the drainage of the "Alhajuela Basin," a name bestowed for convenience on the Chagres Watershed above this dam. The undersluices of these dams will be operated to maintain the determined level of the Obispo Basin, which is the governor. In principle there will be permitted the smallest possible accumulation of water behind the two dams, which nevertheless can safely impound 1,000,000,000 cubic meters, which may be doubled by additional dams higher up river.

There will be no great, high, permanent lakes, no tunnels, no experiments. There will be, instead, large and, except at very rare intervals of floods over 44,000 c. f. s., nearly empty catchment basins, capable of perfect discharge control, which can be effected without the slightest inconvenience to navigation.

The Dam designs advocated are substantially those of the Assuan Dam, which has been perfectly successful in impounding 1,065,000,000 cubic meters. It controls and safeguards the Nile, whose flood-discharge is 475,000 c. f. s. or five and a half times the greatest known flood of the Chagres at Gamboa. The height of these Dams can be kept down if desired by supplementary Dams on the main tributaries above Alhajuela.

Having described the tool it remains to demonstrate its adequacy for dealing with all conditions. The Isthmian Canal report of 1901 estimates that the flood of 1879 may have reached 136,000 c.f.s. at Bohio, and concludes that 140,000 c.f.s. is a safe momentary maximum to use as a basis. This amount is equivalent to 91,000 c.f.s. past Gamboa, taking the usual per cent. of flow here as 65 per cent. of that past Bohio; or 105,000 c.f.s. if the watershed above Gamboa be reckoned at 75 per cent. of that above Bohio, and the run off the same per square mile, or 99,600 c.f.s. by gauging curves of the Isthmian Canal Commission. The average discharge during a flood period may be taken as one-sixth less than the "maximum momentary." The 44,000 c.f.s. in the following equation represents the calculated volume that can be let pass the sluices without occasioning currents detrimental to navigation, as is later shown. The remaining 43,500 c.f.s. (105,000—⅙—44,000) would be the amount which it would devolve upon the Gamboa and Alhajuela Dams to retain for the period of the flood, lasting certainly not over 49 hours. This would demand some 176,000 acre feet, while the storage above Gamboa available is 225,000 acre feet, which may be vastly increased by small increments in dam heights.

It has been said that 44,000 c.f.s. may be allowed to pass the Gamboa sluices even when the greatest flood making conditions exist without producing a current of over 1.8 knots per hour. But six feet per second will not harm the banks. Without injury 8,000 x 2 x 6—4,000=92,000 c.f.s. could be permitted without damage to the canal banks and works. The maximum momentary discharge past Gamboa, according to one official authority, was but 78,614 c.f.s. in the unparalleled flood of 1879; and the average discharge according to his method of figuring would have been 66,264 c.f.s. for 49 hours, but in these projects a possible flood of what would have been 150,000 c.f.s. past Bohio is amply met.

If 78,614 c.f.s. be taken as a basis, the storage required to be provided would have been not over (66,264—44,000)=22,264 c.f.s. for 49 hours, or 90,160 acre feet. In the last decade there was only one flood which reached 37,000 c.f.s. and for it there would never have been any occasion to touch a control gate.

In the last generation—33 years in fact—there have been but five times when any water except for silt-trapping purposes would actually need to have been impounded to keep the canal currents below 3 f.s. velocity.

It may be held as proven.

1°. That the proposed type of dams has the strength and the proposed basins have the capacity to hold any Chagres flood within the widest limits of possibility, allowing a sluice discharge of 44,000 c.f.s.

2°. That from a maximum sluice discharge of 44,000 c.f.s. to a minimum of 0 c.f.s. the Chagres waters can be completely regulated by the proposed dams.

3°. That practically all Upper Chagres silt will be deposited above Gamboa Dam in a special pond, from which it can be easily removed.

DIVIDING THE CHAGRES.

OBISPO BASIN.

This second Chagres control element consists in allowing half of the Chagres flow past Gamboa to go in the direction of Panama, and half to the Atlantic, and in providing for the regulated discharge from the Terminal lakes.

It will be noted on inspection of the map that at Bas Obispo the axis of the Chagres Valley makes a right angle bend, and the Upper Valley lies between Atlantic and Pacific serrated Coast Ridges.

Obispo is almost exactly half-way between the inner ends of the new Lakes "Chagres" and "Panama." The topography admits the excavation of a triangular Junction Basin in form like a railway "Y." Waters entering this Junction Basin (which will likewise be a convenient turning area for large vessels) will naturally flow north to Lake Chagres and the Atlantic, and south to Lake Panama and the Pacific Ocean

In effect therefore the Chagres will have two discharge channels, both running from the Junction Basin to a large lake, each channel with an initial minimum water section of 8,000 sq. ft., as before mentioned, or 16,000 sq. ft. in all.

The Commission reported that 15,000 square feet of sectional area would be needed to carry the volume of the Chagres without erosion to the banks or detriment to navigation.

In the chapter on Engineering Constants it was demonstrated that a satisfactory navigable prism must be at least 8,000 square feet in area. If the Chagres is sent down two different channels to the two seas, each channel of 8,000 square feet, there is given the river an effective channel of 16,000, or 1,000 square feet more than was judged ample.

CURRENTS IN OBISPO TRIANGLE.

In the determination of "Constants" which preceded the discussion of measures in this book, it was shown that a 3-feet per second current was not detrimental to canal navigation, Suez presenting currents sometimes double this conservative figure. On account of the size and shape of the Basin there will be very little current in its area and none against the side of a passing ship.

Each outlet to the Obispo Triangle is to measure at the outset 8,000 square feet, 16,000 square feet in all, hence the two channels will pass 48,000 cubic feet per second. The area of the water-shed of the Rio Obispo is officially stated to be 38 square miles. Its waters will be led to the Obispo Triangle. The maximum discharge from the water-shed may be reckoned as 100 x .86 x 38=3,268 c.f.s. The maximum flow gauged in 1900 was but 1,177 c.f.s. In October, 1893, however, the rain gauge recorded nearly 20 inches of precipitation. Let us assume that in such a rainfall as that of 1879 the Obispo Triangle will receive from its local watershed 4,000 c.f.s. In such a case 16,000 x 3 feet = 48,000, less 4,000 equals 44,000 c.f.s., may be suffered to pass thr ugh the Gamboa sluices in the absolute certainty that no currents exceeding 3 feet per second in the canal between Lakes Chagres and Panama will transpire on this account.

A very small head will give a discharge of 40,000 c.f.s. from the basin, 20,000 c.f.s. through each outlet, and will occasion a velocity of only 2½ ft. per second, or 1½ knots per hour. This is less than frequently prevails in the Suez Canal between the Little Bitter Lake and Port Tewfik due to the Red Sea tides. Hence the sluices of the Gamboa Dam can be allowed to pass such large volumes of water that under the worst conditions the catchment basins above could not be nearly filled and they will possess factors of safety against any fresh contingency. There need be no cascade into Obispo Triangle from the Gamboa Sluices—and if there were, it could do no harm—being only picturesque.

The present conception is not, then, that of a "canal," but of a canalized river with two diverging outlets, each leading to a large, easily controlled lake and discharging, one into the Atlantic, the other into the Pacific.

CURRENT EQUALIZATION BY EXPANDING CHANNELS

There are just two further questions, the currents and silting that may be produced between Obispo Triangle and Lakes Chagres and Panama. The turning of the summit section of the Canal into a canalized river enforces consideration of currents. It is no longer a still-water canal; it is in fact a deep, splendid, slow-moving river whose flow must be considered. In the central sections are affluents which ungoverned might produce increasing currents.

Between Obispo and Bohio, the affluents nowhere enter the canal directly, but reach first a loop of the Chagres. The channels northward to Lake Chagres and southward to Lake Panama should have a section adjusted to the added run-off of the area traversed. It is a substantially correct assumption that the mean effective width of the Canal watershed is about the same either side of the Dividing Basin.

The fundamental method of equalizing the current in a flowing stream has been carefully studied abroad, and, to a lesser extent, in this country. But in general the science depends on the expanding of the cross-section in the right ratio to normalize the currents induced by an increase in volume from affluents.

From the Junction Triangle to Lake Chagres and to Lake Panama the water section widths will expand at a small coefficient rate to take care of the central valley drainage which is allowed to enter the channel. Practically the same low velocity of flow at all points can be thus scientifically assured as in the regulation of tidal rivers like the Weser, Scheldt and Brisbane.

ATLANTIC CHANNELS.

If Lake Chagres be established at about the 25 level, it will reach a point 5/8 of a mile below San Pablo and 5 5/8 miles from Obispo Triangle. Below San Pablo all drainage flows into the expansion of Lake Chagres or slack water in the old channel of the river. Therefore, the canal north of Obispo Triangle needs to have its channel compensated for only five small affluents of the minor class, and through less than six miles.

Taking for the Interior Section, as a co-efficient, a maximum run-off of 100 c.f.s, per square mile and reckoning the area tributary to this 5 5/8 miles of canal as 27.5 square miles, it is desirable, in order to secure a uniform 3 f.s. flow, to gradually expand the section from 8,000 square feet to 8,916 square feet. Naturally all the factors of the question must be definitely determined before the final amounts and locations of the expansions are settled.

Below San Pablo, Lake Chagres and its slack water constitute an expansion of the canal section so great as to nearly eliminate the need of sectional increase. The writer considers it best not to close the river channels where the canal cuts off bends.

All the tributaries in this section, except the Rio Caño, are small and can be led to old river loops with only the works necessary for insuring that neither silt deposits nor objectionable local currents shall occur at junctions with the Canal.

The Rio Caño has a large watershed, a recorded maximum discharge of 1,640 cu. ft. per second, a mean discharge of 335 and a minimum of 17 ft. per second. At a suitable site, as indicated, an Insubmergible Under-sluice Dam shall be built capable of perfectly regulating the discharge of the Cano Basin.

The few creeks between Bohio and Obispo will be led into the Canal, each with suitable small auxiliary works, channels, débris-dams, or weirs and aprons, to prevent erosion and the carrying of silt.

At Bohio gap the area of the waterway for this level under this test would work out 100 × (250—40) + 24,000 ÷ 3 = 15,000 square feet. But by the Cano Dam run-off 90 square miles of its watershed is put under sluice control. By this effective means the water-way at Bohio is reducible to 12,667 square feet. The Canal and the section of the old channel will together make this. Provision sufficient in cuts between San Pablo and Bohio must likewise be made, utilizing the old river channel and the diversions excavated by the French to keep down the quantities of excavation. Lake Chagres at 25 or 30 will submerge considerable swamp areas above Bohio.

PACIFIC CHANNEL.

The expansion toward the Pacific may be similarly calculated. The Canal watershed of the Culebra Divide from Obispo to Pedro Miguel may be estimated at 8 miles long and one mile wide, omitting the Rio Obispo, whose waters reach the triangular basin, and the reservoir watershed of the Rio Grande.

The rainfall of the Culebra Divide is about 86 per cent. of the Interior section as shown by the comparative Table of Rainfall. Hence we may reckon 100 x .86 x 8 or 688 c.f.s. and the area of the section at Pedro Miguel should be $8,000 + \frac{688}{8} = 8,230$ square feet. The distribution of this small expansion in the 8-mile stretch will depend upon the details of terrace and tunnel drainage and the points at which water is permitted to enter the Canal. Below Pedro Miguel, Lake Panama, a veritable expansion, absorbs all the remaining run-off of the Pacific watershed.

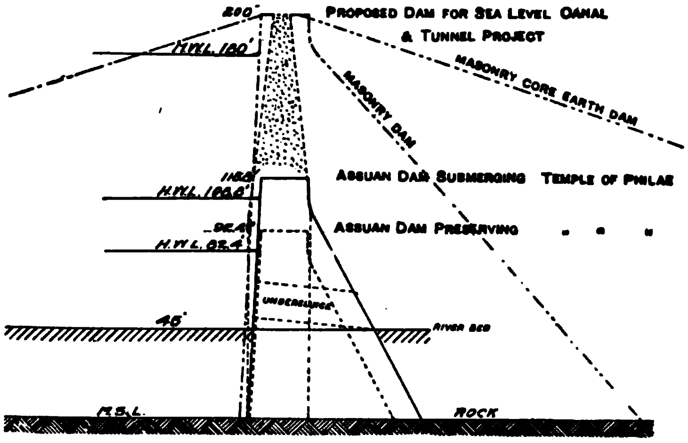
BANK SLIPS.

The only locality where a slip can occur is in the Culebra section, where very special care in proper terracing, and in surface and tunnel draining the slopes is imperative. The principles should be employed whose soundness has found such happy application to the phenomenal landslip which recently jeopardized the reservoir at Portland, Oregon. Should a serious slip occur, blocking the South Channel the three dams afford the mechanism for obviating any damage to the Canal if a severe flood supervened before such a slide was cleared by dredges, because the north channel from Obispo in connection with the control afforded by the three dams can handle any recorded flood without harm to the Canal.

SYSTEMS OF RIVER CONTROL IN FORMER PROJECTS.

In the light of these hydrologic determinations the other method of Chagres control may be analyzed having accurately determined what one system can do.

As a premise it may be stated that there are only two systems possible for Chagres control. One is the solid Dam and Diversion Method. The other is the Under sluice Dam, Empty Basin and Divided Channel Method.



COMPARATIVE DAM SECTIONS UNDER TWO TYPES OF RIVER CONTROL.

SOLID DAM AND SPILLWAY SYSTEM.

Solid earth dams are dependent upon tunnels or spillways to carry off the surplus waters they impound. This is the sole method which has been considered in the first two fundamental plans, the "sea-level" and the "central lake." It is scarcely necessary to describe the system beyond particularizing the types of dams which it includes and which have been considered applicable to Panama.

Masonry Core Dam. Undoubtedly a very satisfactory dam, if it is available, is of this type. In essence it is a wall built on solid rock foundation, on both sides of which are deposited earth, gravel, etc., to give it stability. Such a structure is not subject to percolation, but is quite tight. It is, however, dependent upon *rock foundations* at a *workable depth*. The limit of caisson work is the limit of human endurance of air pressure. In the temperate zone this is at less than 100 feet—in the tropics the range is probably narrower as the strain upon endurance is greater. This factor determines primarily the possible utilization of a masonry core dam.

The Rock Fill Dam. A second type consists essentially of earth deposited in such a way that it is buttressed and reinforced by a rock filling. The most significant design for present consideration is that proposed by the late Geo. S. Morison. It embraces two rock fills made some distance apart across a river, then at a place between them a curtain of puddle is made of watertight material, below which is first driven sheet piling to prevent seepage lower down. The space between the two rock fills is then filled with earth. This is a very serviceable dam where no rock foundations are available, but it has two limitations. (1) Its proportions are necessarily such that for, say, his 90 foothead, the dam must extend half a mile back from the first to the second rock fill. This makes a very large and expensive structure, requiring a long period for execution. (2) The river valley must be narrow enough that the filling be not colossal in volume.

Spillway or Tunnel. It must here be noted that to carry off surplus water a spillway or tunnel is vital to the solid type and problems connected therewith are integral to the Chagres Control question. If no safe site for a spillway exists, the surplus water must be drained through a tunnel. If by reason of squeezing strata, distance, or seriously adverse consequences or cost the latter is unavailable an inherent prohibition is placed on this variety of dam.

SOLID GAMBOA DAM AND TUNNEL DIVERSIONS.

SEA-LEVEL SYSTEM.

There are two potential locations at which the main Chagres control have been proposed. These are the gates which serve as outlets from the upper watersheds, Gamboa and Bohio.

The sea-level system considered that there must be a dam at Gamboa where the Chagres first strikes the canal axis and that the dam must be of the solid type.

The sea-level plan has the initial disadvantage that it carries with it certain serious requirements. To these the conditions are not favorable. To secure any discharge location whatever through the rim of the upper Chagres watershed nature decrees that a lake be flooded to an elevation of at least 175 feet, subject to a rise to 180 feet in flood time. It demands a monster S shaped dam twisting 6,000 feet across the Chagres valley, at Gamboa, looming 200 feet from crest to foundation. Such a dam is theoretically a possibility, though most difficult of execution, and it lowers the margin of safety too far for conservatism. It is the disposition of the discharge that is so questionable. There are three conceivable alternatives—an Atlantic diversion tunnel between the lower and upper Gatuncillo, a Pacific diversion tunnel from the valley of the Chilibre, or spillway with diversions paralleling the canal.

GATUNCILLO TUNNEL.

The Atlantic diversion demands a three and a half mile tunnel to discharge a swift current to riot down the Gatuncillo and then parallel the canal to Manzanillo Bay. It would mean something to turn an 1879 flood down the twenty mile tropical valley, whose drainage channel is utterly unprepared to take care of such an accession of tumultuous bank-tearing waters to its own unknown flood. Unless an adequate water-way be excavated to the tunnel's mouth from near Gatun the expensive diversion channel having almost no slope to Manzanillo Bay must inevitably be choked again and again and again with the vegetable and earth débris of an eroded valley. No provision appears in the sea-level plan or estimate for safeguarding against this outcome.

CHILIBRE TUNNEL.

As a Pacific diversion a possible site was located up the Chilibre, for a tunnel which would not return the waters to the Chagres, but by piercing eight miles of the main ridge would send the waters to the Pacific. In such a tunnel length as this, the cost, the difficulties, and the dangers of stoppage from the volcanic formation are greatly increased. The consequences to either of these tunnels, or to a series of smaller ones, should an earthquake cause a check at the beginning of a large Chagres flood, are appalling. A closing of the tunnel at the beginning of a flood would send tens of thousands of cubic feet of water a second over the Gamboa dam, whose erosive power no dam so built could resist. A breach would let loose over the canal a wave 150 feet high, blotting out all shipping and rendering the canal useless for years until dam and tunnel could be rebuilt. To such a scheme sluiceways or spillways, with all they mean, must be added, near the dam Furthermore, the tunnel does not solve the problem for the watershed below Gamboa which, in 1879, sent nearly 40,000 c.f.s. past Bohio, where dependence must be placed on river diversions.

The "spillway and diversions" as alternative or supplement to a tunnel are open equally to criticism. The Chagres at Gamboa is at an elevation of 45 feet above sea-level. Its torrential waters would be held plastered on to the hillside, with the canal below. For twenty miles the river would thus overhang the waterway. The safety of a twenty-mile septum with a river eroding the entire length is more problematic even than the tunnel.

SILT.

There has been apparently no broad consideration whatever of the silt question in the plans for a sea-level canal. It has been evidently accepted that a plant will be continually occupied in traveling the length of the canal and diversions, for deposits will be made wherever an affluent enters the river and from erosion caused by passing vessels. The permanent cost of this operation, as well as its blocking of traffic, may well be seriously studied for the whole canal, and for the parallel diversions as well as for the debouchment of the Gatuncillo tunnel spillway.

The canal will be in effect at the bottom of a narrow gorge for a good portion of its length, its surface in places 45 feet below the present river, its bottom 40 feet below this, and its banks raw with new excavation. There cannot fail under the tropic conditions of the Isthmus to be the greatest trouble from silt, and much more under this than under any other plan.

BOHIO DAM AND DIVERSIONS.

THE CENTRAL LAKE SYSTEM.

It is inherent in a central navigable lake canal that a dam be constructed at Bohio, or at Gatun. It is desirable that a lockage reservoir lake be made at Alhajuela if the summit level is below 85′.

It is inherent that the main dam be of the solid type.

It is inherent that below Bohio or Gatun the surplus waters of the Chagres drain to the Atlantic by diversions substantially paralleling the canal line.

It is inherent that two or more locks be instituted leading up to the summit level.

Bohio Dam. Bohio has in every serious proposal been selected as the location of the high central lake dam. The Comité Technique proposed a special rock fill struture; the Commission of 1901 advised a 228-foot masonry-core dam, but their data gave bed rock at 128 feet below the sea. Recent revelations show that it is only to be found 163 feet below the sea, far beyond practicable caisson work.

The Commission of 1904, in its first annual report of December, says:

> "It is necessary to make further and extensive investigations to determine at what section of the geologic valley the bed rock offers the most advantageous location. The borings thus far made disclose the bed rock to be somewhat lower than is desirable, and the chief engineer testifies: 'It is very uncertain what will be found when more borings are taken. It is entirely theoretical. The results thus far have been disappointing. The average depth bored without finding bed-rock has been 160 feet.'"

The result of this, to the conservative engineer, is to eliminate the advisability of any dam here of over 40 feet head. No masonry core dam should be essayed. A 90 or 60 foot head dam of the ordinary rock fill order would lose a crucial amount of water by percolation. The Morison type runs to vast volumes and long construction periods.

It is self-evident that an accident to this dam must precipitate the impounded lake upon the lower country, a disaster which would be memorable. In a country where earthquakes are not uncommon, a breach in the high-head Bohio dam must be an ever-present menace.

To construct an earth dam, furthermore, in a narrow valley, without first diverting the water, is a hazardous undertaking. A temporary tunnel at the low-water level would be necessary, or a spillway through the lock.

Under a low level—say the 30 foot plan of last winter, there would be provided only a comparatively small and inadequate lake to regulate the Chagres. The change of level produced by flood would be great, and there would be added dangers of flood currents. The difficulties of construction, too, would be great. When completed there would still remain a long stretch of sea level canal below the dam, and the difficulties in the diversion of various streams on both sides of the channel.

Discharge. The surplus waters from the central lake, if made above Bohio, must escape by the Giganté spillway. But they return to the Chagres River, making the parallel diversions necessary.

Silt. Beyond the flood damage intrinsically liable from a river alongside a canal there is the certain problem of sediment. While the upper Chagres is officially designated as non-silt bearing, its flood condition is little known, and in all probability there is much sediment brought down. The rank vegetation also prevents at the present time any large erosion. But excavations and clearings must alter this situation Banana plantations would expose a large area to erosion. So that the silt problem is serious here also and is not well provided for.

The map shows the portion of the canal line near Obispo and from Mindi to Bohio, also where the silt and erosion question is most important.

Alternative Gatun Dam. Gatun has been explored and found wanting as a high head dam location by every commission from the earliest down to the present. The reason is that the great width of the valley and the absence of solid foundations make such a high dam and lake as proposed too hazardous for serious consideration.

A scheme for a Morison type dam 120 feet high and 8,000 feet long and tailing along the Chagres 2,000 feet has recently been proposed for Gatun. As was shown by the borings no rock is found at 175 feet below the sea.. On the formation that exists there may safely be built a Morison type solid dam up to 40 feet head. But beyond that it is increasingly questionable in the light of the safest engineering practice in the tropics.

CONCLUSIONS.

Hence granting that the Gamboa and Alhajuela sluice dams have the power to hold their discharge to 44,000 c.f.s., which is unquestionable, the following results from this Channel division:

1. Where every one of the old plans of necessity and by their very natures included a canal paralleled by river diversions on both sides, which had to be so extensive as to be equivalent to digging two canals alongside the navigated one, the canal here advocated avoids this needless duplication, hence all the money and labor put into paralleling with various diversions from sea to sea can be saved or be spent on the real channel.

2. No problematical tunnels are required.

3. No detrimental currents whatsoever need occur.

4. A large central basin well suited for turning and passing, and forming a natural meeting place for ships, is furnished.

Having measured the two systems, under the various plans which embody them, against actual conditions, it is seen that the solid Dam and Diversion System is inadequate and creates conditions hazardous in construction, in stability, in maintenance and in the interests of navigation. By the old system, neither the currents nor the silt depositing proclivities of the Chagres are in harness nor is the river always compelled to do the will of men. Its flood and freshet relation to navigation cannot be safely left automatic because the dangers of high head will forever persist. When this most moderate contention is admitted but one thing remains:—the Empty Basin and Divided Channel Method, new and original with the author, but sure and safe and not employing a single element not proved by unimpeachable experience and conspicuous example.

The currents likewise are always under perfect—if one wishes it, electric—regulation, through flood or drought. "Unimpeded navigation during all floods not exceeding 75,000 cubic feet per second" was claimed for the Project of 1901. Under this new Project even the 140,000 cubic feet per second of 1879 need not occasion a velocity of two and a half feet per second, because the waters are harnessed, and not let run wild.

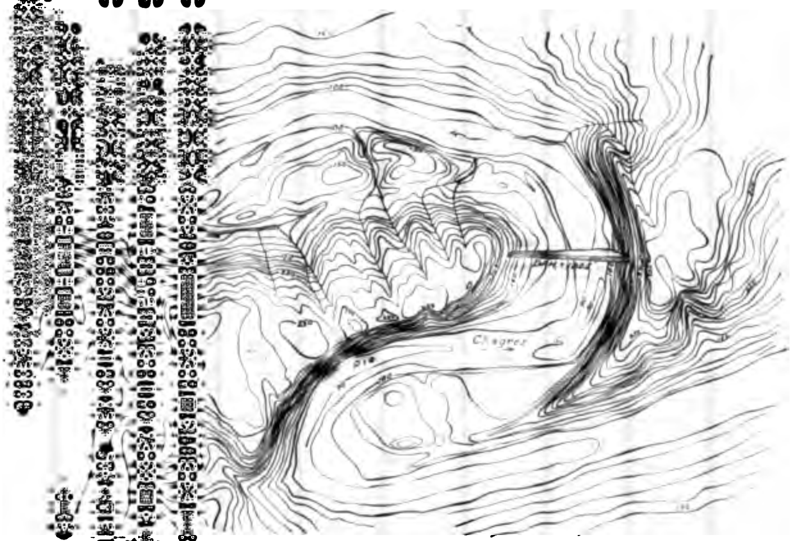
Canvass and scrutinize the records of drought and storms reflected in the tables, the graphic registry of the data gained by a generation of study, the differences between gaging methods; take the lowest minima and the highest maxima and it is not possible to find an hydrologic condition which this, the second method of control, does not surmount with abundant and satisfactory ease. It is not possible to find a day, an hour, a moment when the currents need be undue or when the lockage supply need be inadequate to pass all the tonnage of all the deepwater canals in the whole world.

The silt problem, as it occurs in the Upper Chagres, is met through standard and approved means, by incorporating perfect silt traps, whence the deposit is to be removed by independent and self-loading, self-propelling and self-discharging hopper dredges, such as the writer is now using in raising the grade of Galveston, Texas.

It is recognized that a large economy might be effected by leaving out the Alhajuela and Cano Dams, and that their sluice gates might not be required for service in a decade or perhaps two. It may even be held that a single large dam at Gamboa of the insubmergible under-sluice type will answer all the hydrologic conditions for the practical regulation and canal navigation, under the severest tests of such a flood as that of 1879. But the United States has set itself to a perfect work, and one with every reasonable factor of safety. With the three dams the nation possesses the instruments by which the river can be adequately and at all times controlled. It can be governed by any two of them or by the Alhajuela or Gamboa separately without the possibility of harm to the canal or as much delay to transit as could easily result from the most ordinary accident to a vessel in negotiating the waterway. In the contingency of damage from earthquake, from a canal slip or a flood exceeding that of 1879, by having these three dams, the control of the Chagres is rendered as certain and precise as human prevision can make it. There is in providing three dams no excess of precaution. The goal of solutions and mechanisms should be ideal and the margin of surety should be so great and clear as to lift them high above all intelligent criticism. The writer has set his standard of safety in regulation where no other Panama project can at all rise to it.

In the Nile valley, 500 miles above Cairo, where the rugged hills have closed in to bar the desert, a dam has been built. Below it stretches to the far sea the Old World granary, the land whose soil has been a treasury. The destruction of this dam would project upon Egypt a catastrophe unparalleled in all history.

[illegible] a nation; Atlantis engulfed in an hour—such would be [illegible] all after ages. But under this edifice, holding back its [illegible] of river, the Nile people are as safe and untroubled as



ALHAJUELA DAM SITE.

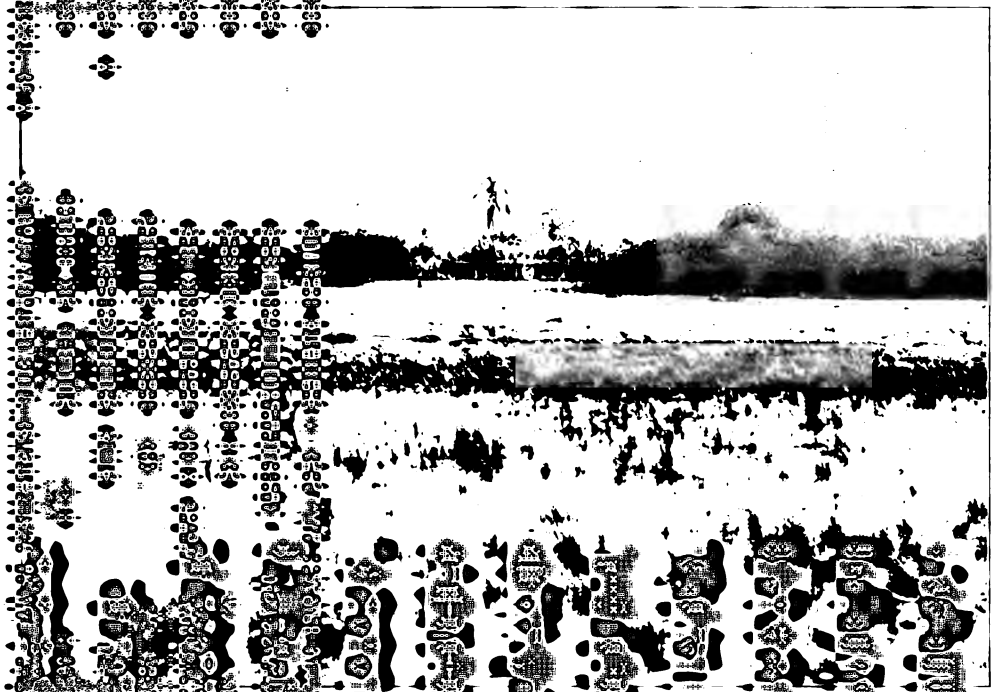
[illegible] granite hills. Through its gates come measured and [illegible] waters, and nine millions of Egyptians live under the [illegible] Dam. In the experience of its success no further word is [illegible] safety of a project incorporating its construction as a [illegible] a full but with a normally empty-basin principle.

CHAPTER V

[illegible] AGRES AND PANAMA

ELEMENTS.

[illegible] ES, TERMINAL SWAMPS SUBMERGED, OPEN
[illegible] ATION 17¼ MILES, 45-FOOT CHANNEL
[illegible] LABLE BY SLUICE CONTROL,
FLOATING PLANT.



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Inspection of a relief map showing the elevations of the canal region reveals two facts:

1st. That the Rio Chagres and the Rio Grande pierce coastal ridges close to their debouchment.

2d. That between these ridges and the central divide are wide swamp areas. These pregnant facts give the key to the end lake project. The net result is that by rock and earth-fill dams totalling in length about 8,000 feet on the Atlantic side and 5,000 feet on the Pacific side at both the Atlantic and Pacific ends low-level lakes can be formed.

The northern lake—Lake Chagres—over 29.5 sq. miles in area and over 11.5 miles long, may extend from Mindi to above Bohio. It will incidentally cover all the lower Chagres Swamps and Pena Blanca, which will be flooded to a higher level, as hereafter mentioned.

The other—Lake Panama—about 5.5 miles long, will be similarly formed from Miraflores to La Boca with an area of 7 sq. miles. It will submerge permanently all of the festering swamps around Panama. Each lake will be entered and left by locking, and the level of each will be adequately regulated by a suitably located Insubmergible Under Sluice Barrage. Such a barrage in its latest and most perfect design has demonstrated its complete success, working on a scale much vaster than is required and without foundations upon rock.

There will be thus created a total of more than 17 miles of what for speed and navigation purposes is practically lake navigation between Mindi and Buena Vista—and between Miraflores and Sosa. This lake navigation will be nearly six miles longer than that afforded by the Lake Bohio Projects.

All tributaries of the Chagres on the east side between Mindi and Bohio will flow into the new Lake Chagres, depositing silt far from the canal.

The western tributaries between the Dam and the Giganté will also empty into this Lake. The waters of the drainage basin of the Pena Blanca Swamp and the Rio Giganté will drain towards the submerged Agua Clara Swamp.

There may be a wide, impermeable and in-submergible bank between the Canal Channel and the Pena Blanca Swamp if Lake Chagres be set below 30′. The level of the water in the latter will be raised to at least 30 ft., which will cover its foulness to a depth of 7½ ft. This height will be readily regulated by a spillway in the Channel between the two swamp areas. No appreciable currents in the track of vessels will be produced by the streams entering the east and west sides of the lake.

ADEQUACY OF STRUCTURES.

To impound, control and make available for navigation these lakes three structures are necessary: 1st. A low-head masonry sluice barrage for discharge control. 2d. A low-head dyke similar to much longer ones in Holland. 3d. Entering locks up to 36-foot lift and of the best dimensions as predetermined in the chapter on Engineering Constants.

The conditions to be met shall be first particularized so that with accurate knowledge the proposed structures may be measured against them. In brief the requirements are:

1st. That the barrages and dykes shall support safely a head up to, say 40 feet. For a 40-foot channel a lesser head only need be supported. But it is proposed to make a 45-foot channel available for any later demand of vessels by mere manipulation of sluice gates. So stresses should be figured with this for a minimum.

2d. That the barrage discharge and control all the water that it could possibly be required to deal with.

3d. That the ship locks be easy of access and safe beyond peradventure.

SITE OF PANAMA BARRAGE AND LOCK.

DYKES AND BARRAGES.

The Dykes.—Low dams or dykes are constructed easily and cheaply by various world-known methods. The Morison and several other earth-and-rock fill forms are perfectly safe and feasible, which is evidenced and proved by fifty higher dams and thousands of miles of sea and polder dykes, river levees and reservoir banks as well as by the containing works of the gigantic storage basins of East India.

If given ample width and height and provided with paved slopes where they are exposed to weather or wave motion; if sheet piling be driven which will form a septum to prevent underflow, and proper provision for water tightness be made by puddle, there can be no possible failure or danger. The dykes may be built cheapest by combined train and hydraulic-dredge operations. The head of water is small and the lakes will be without currents adverse to navigation. The levee will be much more substantial and more safe than that, for instance, which protects New Orleans, or which for centuries has bounded the vast irrigation lakes of India.

The Barrages. The Assiut Sluice barrage has a head of water of 10.2 meters, 33.5 feet, and is built on the alluvial soil of Egypt. The Panama or Chagres Barrages could be installed to the proposed head on any Isthmian foundations. But here the rock of the enduring hills exists on the exact sites giving the best locations for the proposed structures.

DISCHARGE.

At Mindi. As there are no records of the discharge below Bohio, an estimate of the water flowing into the basin of Lake Chagres can best be made by adding to the known flow past Bohio the amount contributed by the Lower Chagres [illegible] past Bohio averages 4,798 c.f.s., while the minimum is [illegible] num momentary is calculated to be 140,000 c.f.s. The [illegible] of sustaining the determined head of water in the lake. [illegible] to discharge the 22,000 ft. sec. from the Gamboa reservoir [illegible] Chagres watershed between Gamboa and Mindi. This is [illegible] or 117 per cent. of the Chagres watershed above Gamboa. [illegible] reckoned at 66,264 c.f.s. for 49 hours, 117 per cent. of [illegible] 22,000 = 99,527. If the highest maximum of 100,000

[illegible]

[illegible]

Miguel, Rio Caimialle, Rio Cardenas, Rio Curanda; on the West side: Qsa. Mallejan, Rio Cocoli, Rio Velasquez, Rio San Juan, Rio Farfun.

The Rio Grande watershed is 85 square miles in extent. The maximum, average and minimum monthly fresh water discharge of the Rio Grande watershed is estimated approximately as follows:

Maximum Discharge	8,614 c.f.s.	(estimated)
Mean "	325 c.f.s.	"
Minimum "	0	(observed)

To this will be added the quota which the Chagres River sends to the Pacific. The discharge to be calculated for is the potential maximum 24,000 c.f.s., contributed by the Chagres, plus the maximum flood discharge of the Rio Grande which may be taken at 8,600 c. f. s., or 32,600 c. f. s. Thirteen standard sluices will completely control this discharge, but twenty may be advisedly provided and the locks may act likewise as a safety valve.

LOCKS.

A lift of 36 feet as is shown in the chapter on constants is conservative and eminently efficient. For locks, rock foundations are desirable, but not necessary. At Antwerp, Liverpool, London, Wilhelmshaven and Calcutta (to mention a few conspicuous examples out of many), are enormous docks, quays and locks, which have been built on foundations of ordinary earth and sand or clay; where the tidal range is from 14 to 25 feet. If the lock and barrage sites were on the Chagres alluvial, these necessary structures could still be safely built and worked as they are at Assiut on the Nile and at the great ports named above. But in the chosen locations there exists solid rock.

The Lock and Barrage may be separated or combined. Preference is given to a combined lock and sluice barrage and to the submerging of the largest practicable area of the Chagres swamps. This entails locating the dyke which closes the mouth of the Chagres as far down stream as the local conditions admit and dictate. Such a policy is directly in line both for bettering the sanitary conditions and for enlarging the lock storage capacity of the Chagres Lake. This preferred alternative plan is with both lock and barrage at Mindi and the Dyke at a point on the Chagres. Though as an alternative the Chagres Lake overflow could be discharged through the old canal bed between Mindi and Christobal, or through the Chagres.

GATUN CUT OFF.

The idea favored by the late Mr. Morison, to put a lock at Tiger Hill and carry therefrom a 26-foot level to Bohio, has been advisedly set aside because it necessitated carrying the canal across the Chagres morasses between embankments. This proposition was officially dealt with in the following report:

> "THE TIGER HILL CUT-OFF. Mr.—— is also charged with conducting surveys and examinations to obtain data to enable the Commission to determine the advisability of the construction of what is known as the Tiger Hill Cut-Off, an alternative plan for the location of the axis of the canal between Bohio and Gatun, suggested by the former Isthmian Canal Commission.
>
> The result of his examination does not seem to justify changing the location of the canal by the adoption of this cut-off. While the length of the canal would be shortened, it is doubtful whether the advantage obtained thereby would be sufficient to justify the increased cost of construction, particularly when consideration is given to the fact that the amount of rock and other excavation will be largely increased, and that the canal for a portion of the distance would have to be carried across a swamp between two embankments, the success of this construction and the cost thereof being not possible of previous actual determination. The above applies to the 30 foot level. In case a sea-level is decided upon, the cost of the Tiger Hill Cut-off will be largely increased."

But when a Lake Chagres is created at a 27-foot level or more, it becomes possible to make the author's canal shorter by about 7,200 feet than any of the others. The curvature between Gatun and Bohio is reduced 76° 21′, and the transit time of it is diminished nearly a quarter of an hour. This new Gatun Cut-off will not pierce Tiger Hill as Mr. Morison desired to do on account of the lock he proposed there, but will avoid any cut of over 10 or 15 feet as appears from the contours, by keeping to the westward a few hundred yards. The material to be excavated is readily dredgeable and the bottom of a 40-foot channel is above the plane where dense refractory clays are usually found in the Lower Chagres Valley, at — 18 feet. These advantages will be secured at the cost of a moderate extra excavation as shown by the comparative profiles. An accurate determination of the amount needs only the working up of data which have been secured but not considered at all by any one with reference to this interesting and attractive alternative location through the lakes. In the search for the best American Canal it is urged that this alternative location here first proposed be given a careful consideration in all its relations.

LEVELS AS RELATED TO STRUCTURES.

As was generalized in the chapter on Constants, the level of these lakes will be determined by the standard head on structures, which, for instance, may be set at 35′ or 36′. With—8.5 as the low ocean plane for the Panama terminus the allowable summit level would be, say, 26.5 ft. In a single level canal, with two terminal locks this would be the determining feature for lakes Panama and Chagres.

For a four lock summit level canal this would make available a level of about 33.5 for Lake Chagres. Thus the levels might be Lake Chagres 33.5, then an intervening summit level, and Lake Panama 26.5.

Though not in accord with the principle of "one lock to one level," it is not impossible that the various sites indicated on both sides may prove to warrant employing one or two locks at each end, and setting the level of Lake Chagres and Lake Panama still higher. This would greatly reduce excavation and, by lengthening the lake navigation some miles, reduce transit time. If admitted, another alternative would be to employ a 45-foot lock on the Atlantic side and two low lift locks of about 27 feet each on the Pacific end.

CONCLUSIONS.

By manipulating their sluices the levels of Lakes Chagres and Panama can be raised and lowered. They can be reduced to a sea-level plane or even below. The ruling depth on the other hand can be increased to some 45 ft. without a cubic yard of dredging or other material expense, and without impairing the safety or efficiency of a single element of the project. This is simply a matter of original design and of Dam and Sluice Control.

Such a margin of allowable head exists, however, that should a higher level at any future time be desired, an additional five or more feet will doubtless be found practicable when all structures have been consolidated and proved by time.

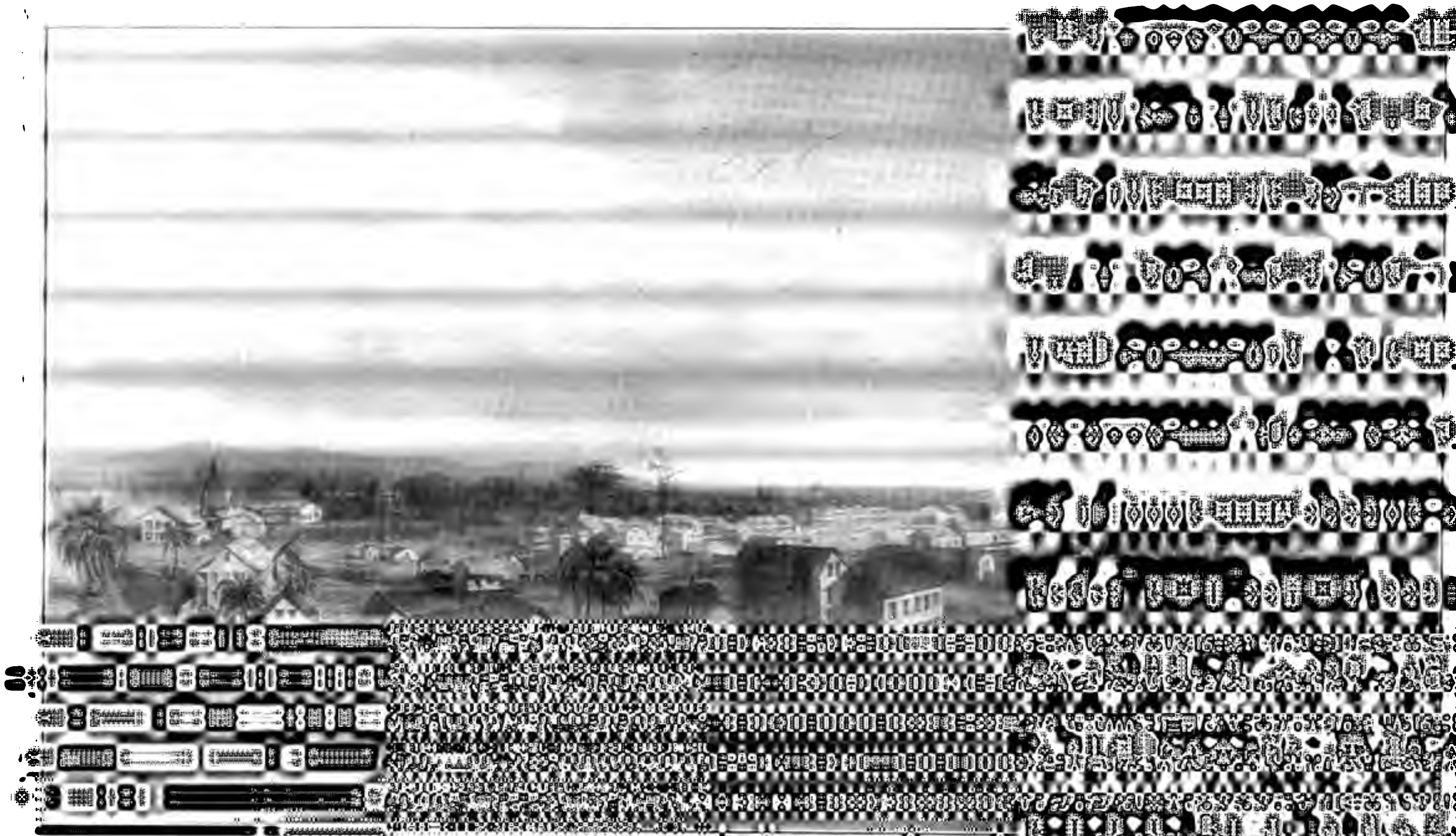
It is therefore evident that barrages and locks as proposed could be installed were the foundations of alluvial earth as in Egypt, Europe and India. But the foundations for the proposed barrages at both termini, for the locks at Balboa and for those at Sosa are *solid rock*. The conclusion is inevitable therefore that the practicability of the proposed system is demonstrated.

In respect to the creation of terminal lakes, it must be conceded that it is in this regard feasible and very easy of execution. Operation, too, will be of the highest simplicity, and a Superintendent in his office at Panama can, by moving a control switch, regulate the level of the lakes and of the canal. By electrically manipulating their sluices the levels of Lakes Chagres and Panama can be raised and lowered. They can be reduced to a sea-level or even below. Enormous and safe storage in both lakes and in the canal can be insured against months of drought.

There is but one natural source of supply for this water, the water-sheds which provide it. The supply is determined by the streams existing and the rainfall which keeps them fed. Barring such items as percolation and evaporation, the amount is measured by two factors, the discharge of the river and the storage capacity of the lakes and canal. These elements are integral and vital for all lock projects. But they are not so equally for all.

ing the self-same territory and the self-same elements. The facts and data regarding the rivers, their discharge, currents, velocities, etc., remain identical for each and all. He adds storage areas which the rest ignore. These lift his designs to a position of guarantee in regard to adequate supply, posssessed by no other lock project whatsoever.

The sites of the dykes are incomparably better as to foundations than those of thousands of miles of dykes and levees in Holland, in Belgium, Egypt, Italy, India and America. The excavated hill sites of the proposed locks and undersluice barrages at Limon Bay and Panama are situated where for untold ages the formation has, without artificial aids for distributing weights over greater areas, borne in the hill masses themselves several times the pressure per square foot which will be imposed by the weight of the projected works, the water and the largest vessel the locks will ever enclose.



CHAPTER VI.

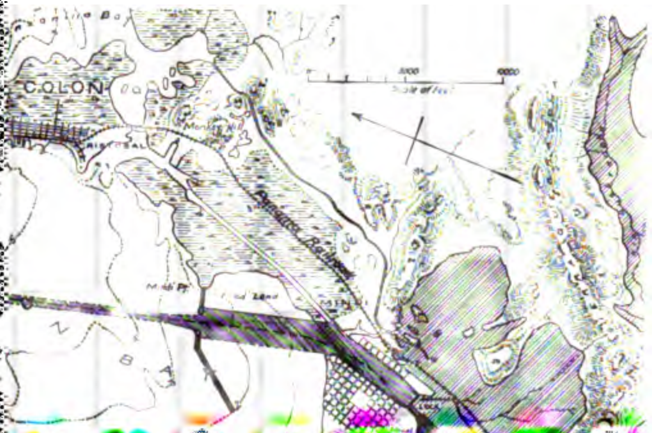
[illegible]RMINAL HARBORS.

THE HARBOR OF BALBOA.

ELEMENTS:

[illegible]OR, INNER FRESH-WATER HARBOR, NEW [illegible]SITE, LOCKS, BARRAGES, DEFENSES.

[illegible]st satisfactory Atlantic canal terminus, for providing an [illegible]rtificial Lake Chagres, and for securing the best possible [illegible]he following program is advocated:



[illegible]

[illegible]-foot [illegible] of

2. That Colon as the Atlantic Canal Terminus be abandoned in favor of a new location at Mindi Gap, and that a new town site, Balboa, be established on the sanitary hill slopes.

3. That an outer salt-water and an inner fresh-water harbor and naval station be established, the two latter in Lake Chagres behind Jaramillo Hill.

LOCATION OF ATLANTIC TERMINUS.

Christobal-Colon, on Manzanillo Island, at the eastern entrance to Limon or Navy Bay, is the present Atlantic terminus of the Panama Railroad. This site is now—as it was fifty years ago—the nearest to deep water. But the writer does not subscribe to its selection as the best site for the permanent Atlantic Terminal city, because new and dominating factors which did not exist when Manzanillo Island was adopted as the railway terminus have arisen and must be given due consideration.

The lots of Christobal-Colon are chiefly owned by the U. S. Government through its possession of the Panama Railway. Most of the town buildings are of a flimsy and unsubstantial character. It is a valuable and convenient base for construction operations and for the commercial use of the railroad for two years until Lake Chagres and its entering lock are opened.

No one will want to live or do business where the present Colon is located when he can have highly attractive and sanitary conditions, and real commercial activity, at a new city on the Mindi Hills.

It is folly also to not put upon the steamer's ocean voyage the distance to the head of Limon Bay. In these days one does not plan to conduct freight or passengers over superfluous railway mileage, and the canal headquarters stations should be at the Terminal Locks, not at the infected, saturated site of Old Colon.

LOCATION OF BREAKWATERS.

Limon Bay—assuming that the new location of the canal at Mindi be adopted—affords scope for a great variety of breakwater locations.

The throwing of two great arms across the mouth of the bay with an 800-foot entrance between is superficially an attractive project. They would enclose a magnificent area of 6,800 acres—10.6 square miles. Physically such breakwaters possess the advantage of making it easier and cheaper to dredge the approaches to the canal because the troublesome trade-wind waves would be excluded; but it means, after all, the greatest ultimate expense, as stone spoil must either be hauled long, unnecessary distances, or be quarried especially for the purpose. The latter would involve very great expense, as these breakwaters are founded in the deepest water and, of course, must be of much greater volume to resist the sea. Breakwaters can be run out from either shore of the bay anywhere south of the outer location above mentioned.

In any other project than those proposed by the writer the port at the Atlantic terminus will be simply a salt-water harbor. Because of better vessel protection, for economy as well as for many other technical reasons, a breakwater position closer in is favored. The Mindi Lock brings Lake Chagres within 4,000 feet of Limon Bay. The cheapest and best breakwater construction will be, as indicated, off Mindi Point, because it is founded in shallow water. It encloses an ample salt water harbor area, 1,100 acres.

All the evidences show that Chagres deposits or littoral drift are now slowly silting up Limon Bay, but the approach channel once dug by sea-going, self-propelling hopper dredges, will be easily maintained, and, further, no more Chagres silt will reach the sea.

The official chart shows that the shortest and most direct route from the New Canal entrance to the nearest point on the 7½ fathom contour would bring the entrance into a harbor made by breakwaters between Colon Light and Point Toro, nearly two miles to the westward of Colon. This fact has a material bearing upon the location of outer breakwaters. The projects of the writer here submitted take cognizance of the facts disclosed to his study by the latest official publications.

INNER FRESHWATER HAVEN.

In combination with this outer salt water harbor, there is available under the system advocated, a unique and most valuable inner freshwater harbor. Its position is entirely sheltered, and is free from any tidal changes of level. Fresh water will defeat the teredo if directed along the new dock front, which here also may be of creosoted timber, or if concrete construction is employed such deterioration as has attended the docks at Port Tewfik on the Suez Canal will be minimized.

DEFENSES.

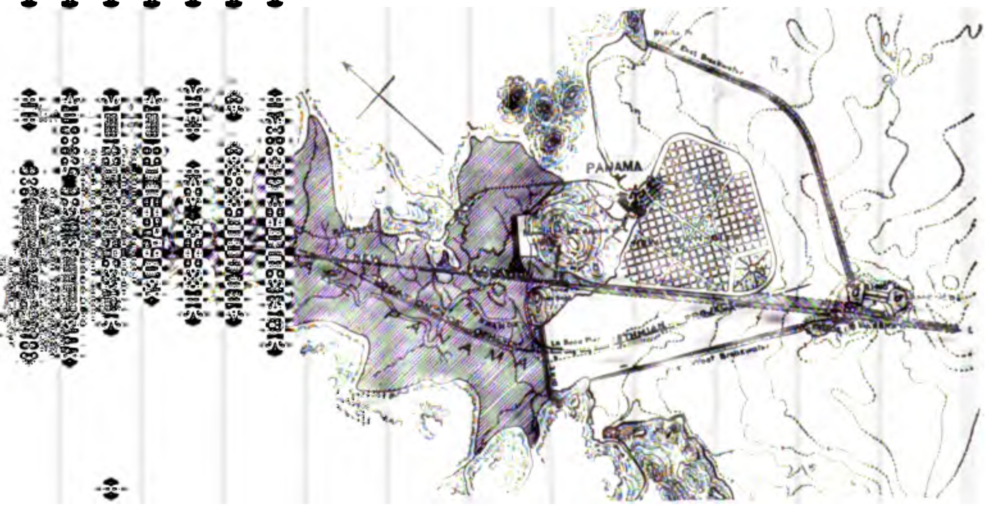
The location of the locks, barrages and naval station inside Jaramillo Hill is far from the deep sea. War vessels must lie beyond the reach of guns on Toro Point, Hala Remo Point and adjacent ridges. The important terminal works on the Atlantic, as on the Pacific end, may be made therefore practically immune from danger.

[illegible] HARBOR OF GREATER PANAMA.

ELEMENTS:

[illegible] INNER FRESH-WATER HARBOR, LOCKS AND [illegible] SITES, NEW PANAMA TOWN SITE, NEW [illegible] ENTRANCE LINE, NAVAL STATION.

[illegible] ion for the problem presented by these conditions, and [illegible] utilization of the natural factors, the plan briefly out[illegible]d:



THE HARBOR OF GREATER PANAMA.

[illegible] canal line be located from Miraflores, via a lock between [illegible], and through the Isthmus between Naos and Perico [illegible]

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THE PROPOSED LOCK AND BARRAGE.

It has been shown that the central sea-bed trough gives the shortest and most direct approach both to the mouth of the Rio Grande and to the saddle between Sosa and Ancon Hills. A line struck from Miraflores will pass straight through this saddle and between Naos and Perico Islands to the nearest point of the 7½-fathom contour. IT WILL ELIMINATE 66 DEGREES OF CURVATURE IN THE ALIGNMENT OF THE CANAL.

Between Sosa and Ancon Hills, therefore, is the best location for the lock and barrage. These should be combined because the fresh-water discharge can most profitably and beneficially be directed through the channel actually navigated and adjacent to the docks of Greater Panama. Creosoted piling and timber, instead of expensive steel or concrete structures, can be safely employed and will involve much less capital outlay.

Between these hills is also a good and suitable formation in which to found the lock and barrage construction. Above the La Boca Pier can be readily thrown the dyke which will define Lake Panama, employing the principles evolved in the conquest of Holland from the North Sea.

PANAMA LOCKS.

Twin locks are proposed, 1,050 feet in the clear, and 105 feet wide. They could be built—as could be also the barrage and La Boca bank—so as to hold Lake Panama to a level of 30 feet, if desired. It appears, however, to the writer that the best lake level to adopt will work out probably about + 26.5 feet, the latter meaning a longer and larger lake and less excavation than the + 20 level. The governing factor is the admissible lift of a single lock on the Pacific side.

FRESH-WATER DISCHARGE.

As a result of the proposed Obispo dividing Triangle, about one-half of the discharge of the Chagres past Gamboa, together with the surplus of the watershed of the new Lake Panama will pass through the terminal lock and barrage into the Outer Harbor. This will carry no silt. The mean discharge of the Chagres, determined by averaging the Gamboa records from 1892 to 1901, is officially computed at about 3,200 cubic feet per second, distributed as per table:

MEAN MONTHLY DISCHARGE PAST GAMBOA.

	c. f. s.		c. f. s
January	3,310	July	4,010
February	1,330	August	4,080
March	900	September	3,540
April	1,530	October	4,110
May	3,180	November	4,790
June	3,280	December	4,850

As to these volumes, there will be certain losses from evaporation and seepage, and certain gains from the watershed of Lake Panama. But in round figures one may reckon on a mean discharge into the outer harbor of about 1,600 cubic feet per second. This quantity will keep Lake Panama purified and renewed. When directed along the new dock front it will prevent the destructive works of the teredo, or other marine worms, and the growth of barnacles. It is equivalent to a stream 200 feet wide and 8 feet deep flowing at the rate of 1 foot per second. Naturally it must be remembered that the above figures are averages, and that the actual discharge will be under absolute control, but will be varied according to the rainfall, to the run-off of the Chagres Watershed, to lockage demands, and to other causes.

PANAMA INNER FRESHWATER HARBOR.

Under these projects and designs Panama (and the Northern Canal terminus as well) will possess an Inner Fresh-water Harbor, an advantage absolutely unique in the tropics, and of incalculable value. A single central Bohio Lake, remote from population, would provide nothing at all comparable for convenience and accessibility.

A FLOATING DRY DOCK AND REPAIR WORKS ought to be located in the Lake because the steel will last much longer in fresh than in salt or brackish water, as the comparative condition of the old floating plant along the Panama route sufficiently attests.

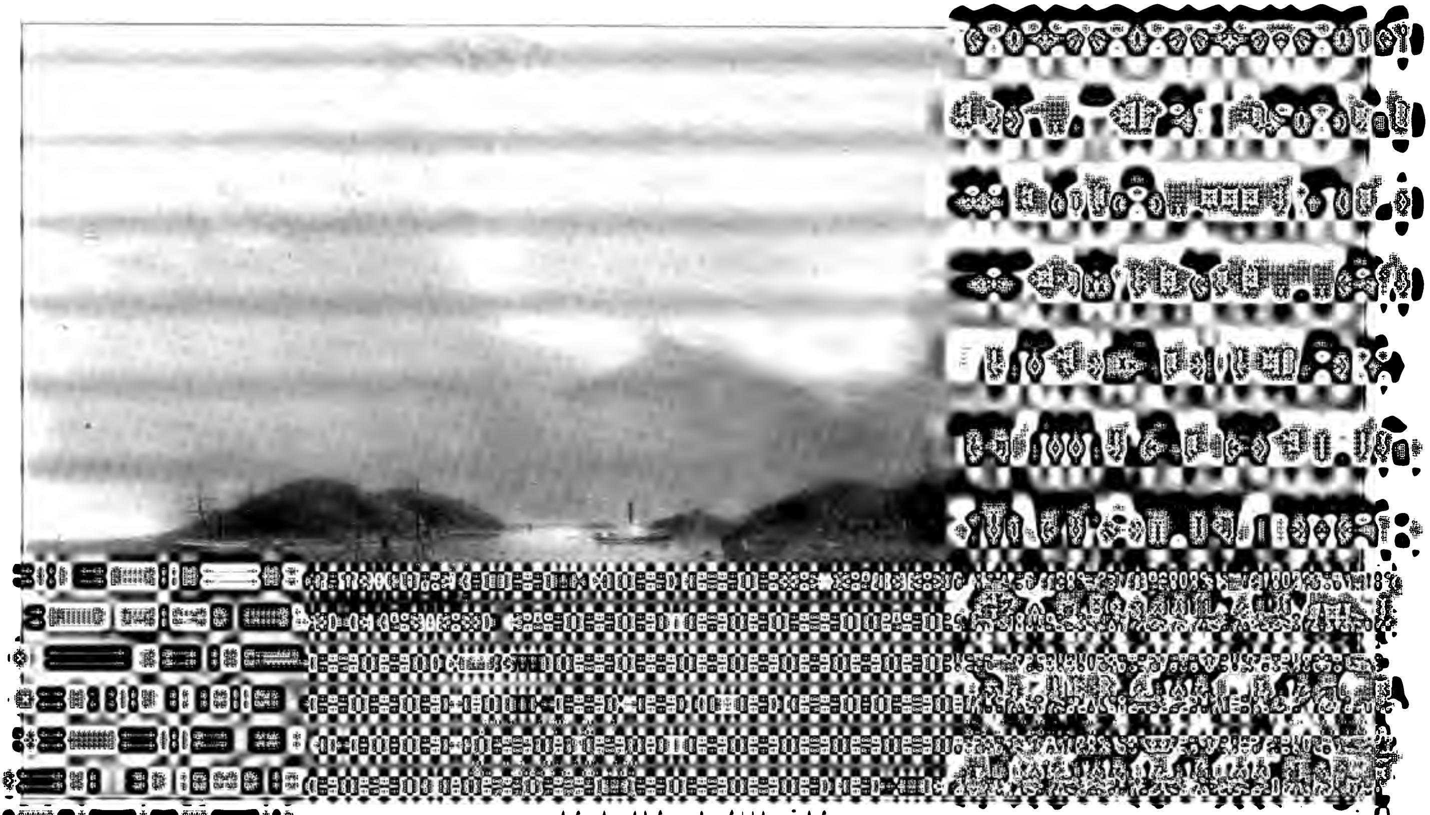
NAVAL STATION.

This too may be established here under the safe shelter of Ancon and Sosa Hills, where hostile shells could not reach it. Few places on earth could be so effectively defended by forts as this new Panama Harbor.

BREAKWATER AND HARBOR ENTRANCE.

The harbor may have one, two or three entrances—east, central and (or) west. The entrance preferred is the central one between Naos and Perico Islands, and shown in full lines on the plan.

In the preferred plan Perico and Flamenco Islands are joined, making the East Breakwater Head, and Naos and Culebra Islands are joined for the West Head. Large masses of trap rock are placed "pierre perdu" with suitable sea and inner slopes, and a roadway space on top.



[illegible] IN PANAMA BAY

EAST BREAKWATER.

This will extend from Perico Island to Petillo Point east of Panama City. It is projected with an angle so that a wide approach is provided into the sheltered haven from whose shores the present piers of Panama project. This breakwater will require 4,700,000 cubic yards exclusive of settlement, and it provides thus much of a spoil area for the rock of the Culebra Section. Its length is 20,700 feet.

The West Breakwater extends from the west side of Rio Grande Inlet to Culebra Island. Its volume is about 2,000,000 cubic yards, exclusive of settlement, and the total length is 13,700 feet.

AREA ENCLOSED.

The total area enclosed by these breakwaters is 5,350 acres, of which the area of the water surface is 3,800 acres and that of the filled land is 1,550 acres. Obviously either or both of these areas can be increased or diminished.

TIDAL PRISM.

Reckoning the reclamation as shown on the plan, the tidal prism will occasion, in a 1,000 ft. entrance, 40 ft. deep at low water, a maximum current of about 1.7 knots at highest spring tide, at mean spring tide an average velocity of 1.37 knots per hour, and at average tide, 1.2 knots per hour. In a narrower entrance these velocities will be proportionately greater. The minimum width should be 800 feet. The tides may be relied on to scour away all the sand in the Naos-Perico Isthmus. The rock or hard clay encountered will require other treatment and methods of removal, but all excavation will be in sheltered areas ordinarily free from wave motions. The tides will assuredly keep the entrance free from silt deposits. The contents of the tidal basin between mean low and mean high water is 2,000,000,000 cubic feet; between mean low and high water spring tides it is 2,700,000,000 cubic feet, and between lowest and highest tides 3,000,000,000 cubic feet.

WAVE MOTION.

The entrance will be wide, and safe, and in the heaviest gales, waves—even coming directly into the harbor—will be absorbed almost immediately that they reach inside the heads.

FAIRWAY AND SAILING LINES.

The sailing lines are substantially straight and will be indicated by suitable outer buoys and lights. The entrance will be one of the most conspicuous, direct and easy to negotiate in the whole world. Protected by Flamenco Island, it will be free from adverse currents.

NEW PANAMA TOWN SITE.

Here is the nearest spoil site which may be made, safely and economically. Its location lies within the arms of breakwaters built to enclose a harbor area and a spoil area, each large enough to answer the demands of commerce and the magnitude of the Culebra Cuttings.

Such a deposit ground can be established and utilized, adding to the domain of the Panama Republic, affording a new and better located and ideally sanitary site immediately adjacent to and seaward from the present town; creating an ocean driveway, a park and plaza system; and supplying as well, docks and the U. S. Naval station so supremely desirable here.

LAND RECLAMATION AND CULEBRA SPOIL AREA.

The writer deprecates the proposal to cover the Rio Grande swamps with Culebra material. It should be deposited nowhere in the canal watershed unless there is a certainty that tropical deluges will not sluice mud back into the channel. It is far better to create a clean, sanitary fresh-water lake, with all such a lake would mean in the construction, operation and maintenance of the canal, and in the health of Panama. The mangrove thickets afford splendid material for fascine mattresses in connection with dyke and harbor works. The writer has found mangrove fascines perfectly sound, after twenty years' use under tidal training walls in the Fitzroy River in Queensland on which he made a special study and report. Moreover, the area of these swamps will hold but a fraction of the Culebra spoil, which in principle should be carried outside the watershed of the Rio Grande. Such a fundamental requirement sends one at once afield.

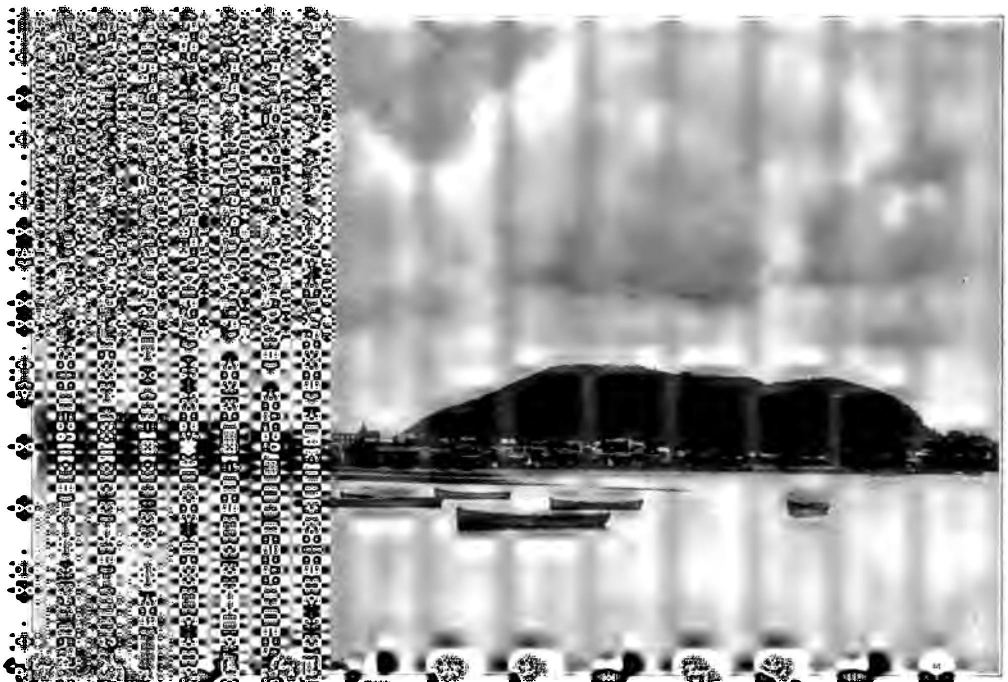
No available spoil areas lie on the mainland to the westward of La Boca Bay, and one must go to the watershed of the Rio Juan Diaz—6 to 8 miles east of Panama, and 20 miles from Obispo, to get away from the drainage basin of the Canal.

If the material dug from the Canal is taken by rail to large sea-dumping vessels, it must then be carried a dozen miles away, so as to insure that the strong littoral drift will not bring endless contributions of mud back to the unprotected dredged channels of the Panama Roads, as is permitted by all other proposals.

Together the Breakwaters will take 7,500,000 cubic yards of Culebra Spoil, adding 10 per cent. for settlement.

[illegible] will utilize, say, 1,000,000 cubic yards. All the balance [illegible] from the summit cut—to whatever depth the Canal be [illegible] distributed for reclaiming land in the harbor area and still [illegible] space.

[illegible] tive extension of the town site has been laid off. This [illegible] a spoil deposit of 56,500,000 cubic yards when filled to [illegible] water.



[illegible] ON [illegible] OF THE [illegible] OF [illegible]

[illegible] use [illegible] a [illegible] Southern

[illegible]

[illegible] property [illegible] Panama [illegible]

Along the west side of the Main Reclamation will naturally be located the deep-water wharves, and the reception buoys. Here may be placed the coal bunkers or the fuel oil supply pipes.

LA BOCA PIER.

This structure will be best utilized in connection with the Naval Station, as it will be off the track of commerce after the Canal is opened.

La Boca Wharf was mostly constructed by the new French Canal Company, but was finished under Railway management. In a sort of juggling operation the pier, built at exorbitant cost and with all the financial vicissitudes incident to that unhappy period, was saddled on the Panama Railway Company, which paid for this so-called "great work" $2,161,552 in cash and 4½ per cent. bonds. On most of this "investment" the U. S. Government is in effect to-day paying 4½ per cent. interest, through being responsible for certain outstanding bonds. In estimating its real value as a commercial asset one must consider that $600,000 was the sum paid the French contractor for building it and probably amply represents the legitimate cost of this terminal. In connection with the harbor projects hereafter outlined, a more convenient and commodious dock can be provided for *one-fifth* the fantastic price to the Railroad. The La Boca Pier was about the only asset on which something could be realized by the New Canal Company, and through the Railroad an open way was available to bring money into the depleted coffers of the French Canal Treasury.

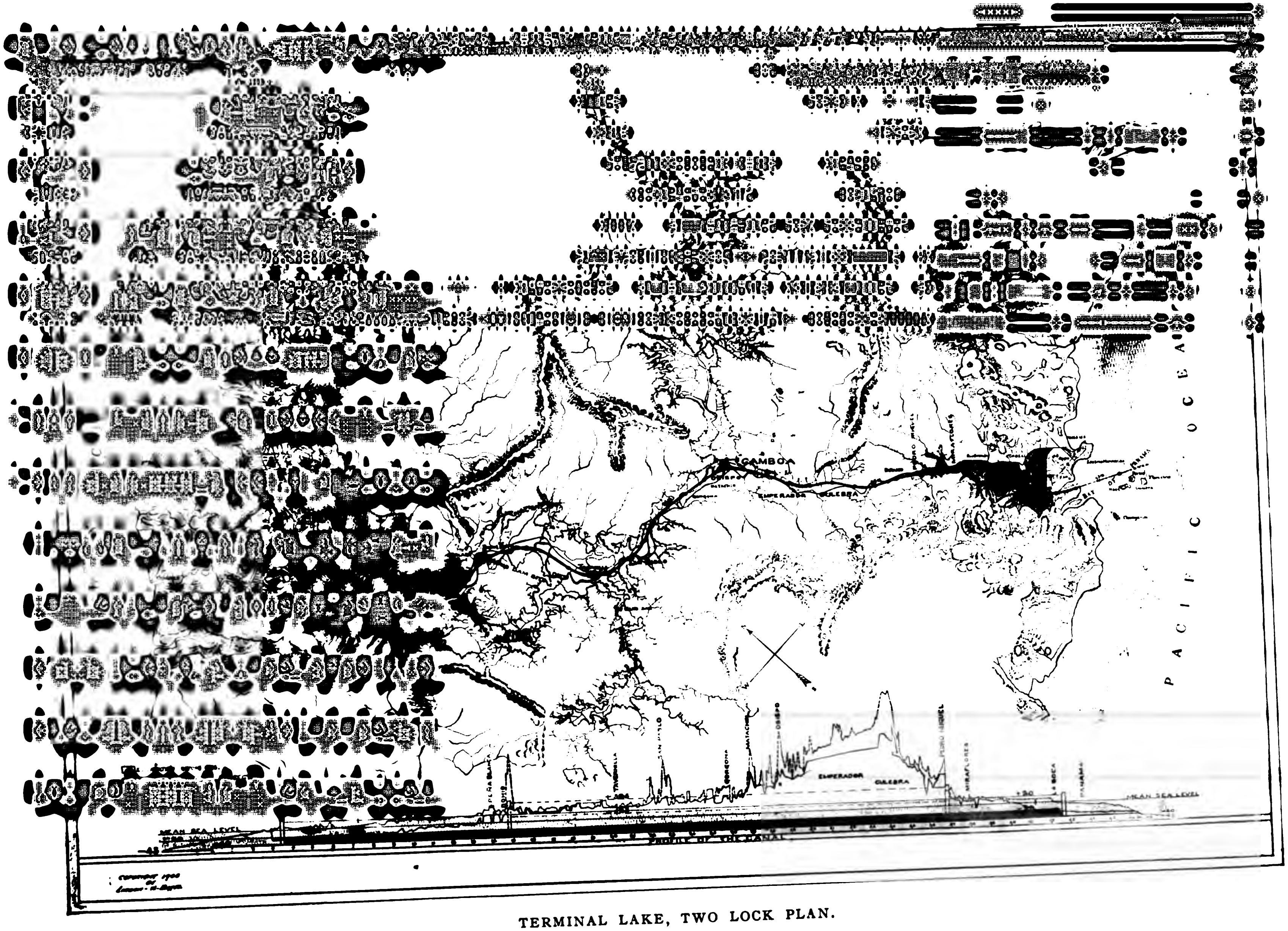
The following are the measurements of the La Boca Pier:

Length....................985 feet.
Width.....................54 "
Depth (at low tide)........26½ ft. (too shallow for deep draft ships).
Width of channel alongside...98 ft.
Railway tracks, two,.........787½ ft. long.
Car capacity...............39
Cranes, ten of two tons, one of 15 tons.
Tonnage of largest vessel yet docked, 4,600 tons.
Manœuvering space.........486 ft. bottom soft mud.

It is obvious that the La Boca Pier is entirely inadequate for the future great port of the South Pacific.

DEFENSES.

Naos, Culebra, Perico and Flamenco Islands, Petillo Point, Ancon, Little Ancon and Sosa Hills, and the salient ridges west of La Boca afford ideal sites for the defenses of an impregnable city.



TERMINAL LAKE, TWO LOCK PLAN.

Project A.

CHAPTER VII.

MAIN ALTERNATIVES UNDER THE SYSTEM.

PROJECT A.

ELEMENTS.

TWO END LOCKS, 27′ LEVEL.

This first plan for the utilization of the new factors and principles that have been established as the fundamentals of the Lindon Bates system is their simplest embodiment.

The harnessed Chagres flows with a regulated slow current into two terminal lakes at 27 ft. There is simply this one level which is entered by the locks situated in the locations that an earlier analysis of conditions showed to be the best.

The 27-ft. level is fixed upon—(1) by the recognized principle of one lift to each level. (2) By the allowed head of 36′, which was chosen as the standard lock lift and head on low containing dams. Since—9 is reached by the Panama tides rarely, this is taken as a standard, 36′—9′=27′ as a level. It is obvious that by so much as these two governing factors are increasable, by so much is the level to be made higher and excavation reduced. But as the empyrical level 27 ft. is eminently safe, it is shown as the standard for Project A.

The structures of A are then those intrinsically part of the system; the dykes and barrages making the two end lakes; the Gamboa Sluice Dam, supplemented, advisedly by others similar on the Rio Cano and at Alhajuela; the Terminal Harbor dispositions as have been described.

Besides its great simplicity, the prime superiority of Project A, is its great lockage supply. It has for use all the water that falls in every basin emptying into the Canal Zone, whereas no project on the Central Lake System can without pumping secure water from any source, save the Chagres watershed above Bohio.

It follows that when any of the central lake projects is shown to have sufficient water, the Project A proposed here will have it more abundantly. In addition to the flow at Bohio, we have the contributions to Lakes Chagres and Panama of the Rio Grande, and of the watershed of the Rio Chagres between Bohio and Mindi, in the latter of which empty two large streams, the Trinidad and the Gatuncillo.

But if in the future there are needed for transit purposes more than is supplied during the dry season, the possible deficiency can be met by using the canal and lakes as storage basins.

Since the mean water supply of the Isthmus is from 6 to 8½ times the minimum daily 1,000 c. f. s., in the dry season, it is a simple calculation to demonstrate that the storage capacity will permit the impounding of enough water by simply regulating the sluice gates and lake levels, to lock more than 50,000,000 tons.

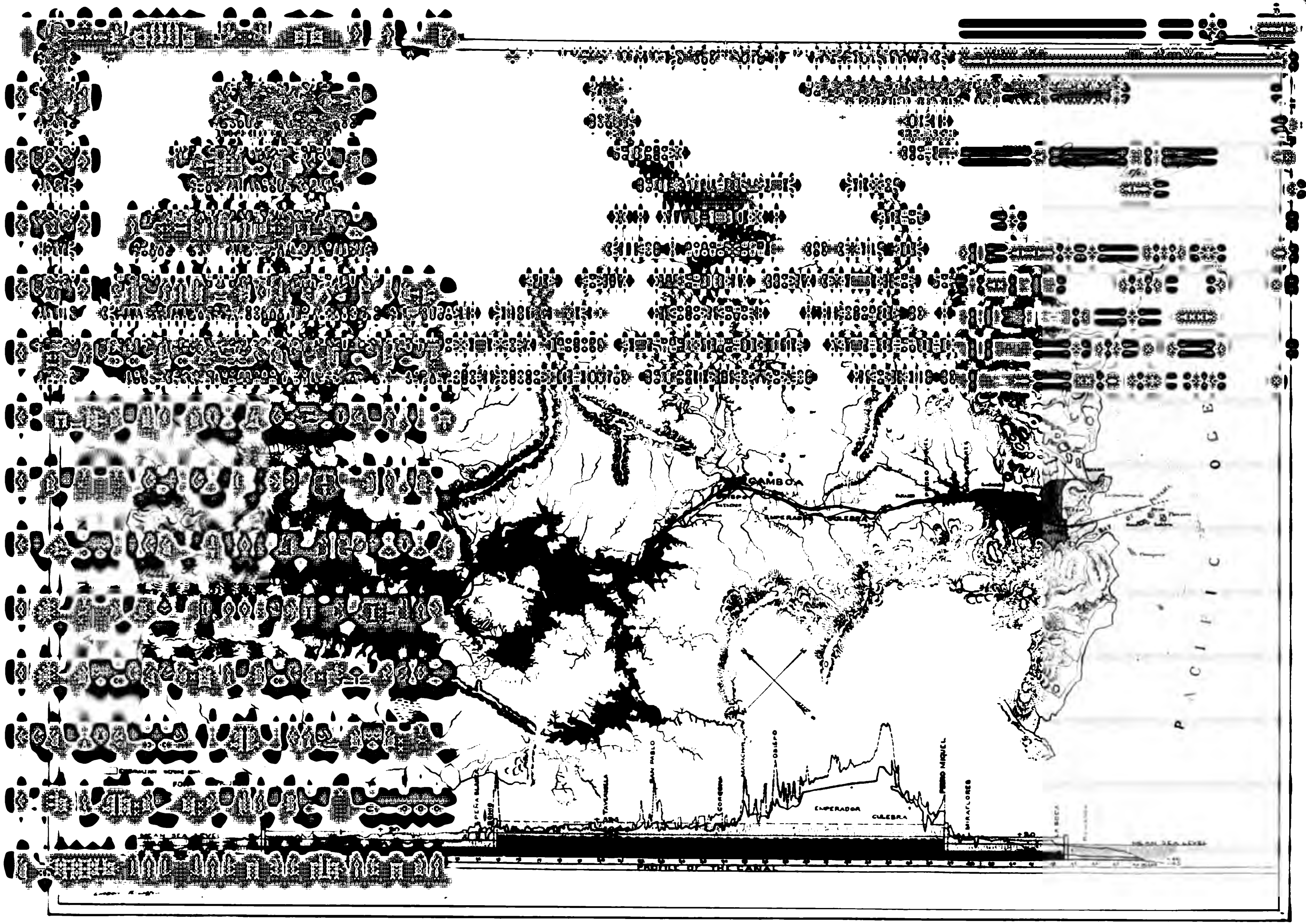
PROJECT B.

ELEMENTS.

FOUR LOCKS, LAKE CHAGRES 33.5′.
LAKE BOHIO 62.5′, LAKE PANAMA 26.5′, PEDRO MIGUEL.
BY-PASS, ALHAJUELA RESERVOIR.

For the four-lock alternative design, which is, fundamentally, the incorporation into Project A of a central lake, the same combination of the two systems of river control is advocated. The Empty Basin and Divided Channel Method, the Gamboa Silt Basin and the Obispo Triangle with its diverging outlets are retained, as well as the essentials relating to terminal harbors and lakes.

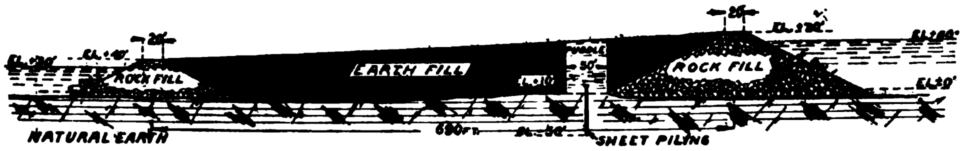
The variations from type A are simply those inherent in a canal of four locks and a higher summit level. The Atlantic channel of the divided Chagres River which requires no expanding section here, reaches the lower plane after first passing through Lake Bohio, at 62.5′ level, made by a dam at Bohio or Gatun. Into this dam is incorporated the "Net Head" principle, which has not heretofore been mentioned. The level of water above a dam measured from mean sea level does not decide the head any more than the necessary height of the dam crest, owing to the net head principle. If the level above the dam is 60 ft. and below it 30 ft., the net head is 30 ft., and this alone counts against percolation possibilities. So that while the water level reached by the dam is as high as that of the Comité Technique and reduces central excavation accordingly, the head is less than half as great because at the foot of the dam is Lake Chagres. The necessary dam is therefore less than half as long, and contains far less volume than a similar dam built for the older project.



TERMINAL AND CENTRAL LAKE, FOUR-LOCK PLAN.
Project B.

As a corollary to this Bohio Lake is a storage provision at Alhajuela, or Gamboa, and a spillway or barrage to Lake Chagres. If the dam be located at Gatun the larger lake makes storage above Gamboa unnecessary.

The level of Lake Chagres will be at 33 feet 5 inches since this is the limit as determined. The Atlantic tides rise only 1.46 feet and so do not permit the lake to have quite the maximum level permitted by the lock and head of water on the dams. Lake Panama, however, is retained at 26.5 feet level since the heads here must include the tidal variation. This disposition makes available a greater saving of excavation in Lake Chagres.



THIRTY FOOT NET-HEAD DAM, MORISON TYPE.

BOHIO OR GATUN DAM.

The French examinations, the work of the 1901 Commission, and the extensive borings of the past 15 months have plumbed the geological chasm at Bohio Gap, and show effectually that bed rock is too deep to warrant the erection on any site of a masonry dam or the masonry core of a high-head earth dam. Bed rock has been proved to lie over 40 feet below where the late Mr. Morison supposed it was. Nevertheless the Morison earth-and-rock-fill type affords a superior design for net heads up to 40 feet under the special local conditions attaching to the canal. He planned a vast Bohio Dam 2,400 feet wide on the bottom and reckoned a seepage of 40 c.f.s. admissible.

It is manifest from the Hazen formula which he accepted, that for a head of 60 feet and the same seepage rate, the dam width at the base would be 1,600 feet and for a 30 foot head it would be 800 feet; if the water on the lower side is at the + 30 foot level and at the upper side at the + 60 foot, the net head is 30 feet.

The figure above discloses to even casual inspection the lessened risk and the economies of construction which, subjected to the same tests of percolation and stability, come to the Dam when Lake Chagres is a ruling feature and there is a net head of only 30 to 40 feet and but one lock at Bohio, instead of two locks and a high dam as in the Project of the Comité Technique and higher locks and a higher dam as in that of the 85 to 90 foot Plan.

The Morison type up to 40 feet head satisfies the conditions at Bohio or Gatun where a masonry-core earth dam should not be essayed, because rock is proven to be below the limit of safe pneumatic caisson practice. It is practicable to set Lake Bohio at 50 feet to 62 feet with one lock, Lake Chagres being at + 20 feet to + 33.5 feet, and the lifts of the locks being 30 feet to 36 feet.

NEW BOHIO SPILLWAY.

To the eastward of the accepted Bohio Dam site lies a saddle in the hill that furnishes a more accessible barrage or spillway site under these plans than does that at Giganté. The former plans could not allow the full discharge so near their canal, but with a lower lake and only the reduced Chagres volumes of this system, it is apparently the better site. Giganté is, of course, likewise available.

PEDRO MIGUEL, BY-PASS CHANNEL.

On the Pacific side Project "B" embraces a lock at Pedro Miguel, the head of Lake Panama.

To carry the excess Chagres water past the lock a By-Pass-Channel through a natural creek bed will leave the canal above the lock and discharge over an apron stepped to prevent cascade action. An under-sluice design will govern the by-pass at will. The sluices of the locks at Bohio and Pedro Miguel will likewise be safety valves for the summit level.

ALTERNATIVE GATUN DAM.

As an alternative to a Bohio Dam, the Gatun location is available on the net head system. The Gatun-Bohio Lake may likewise be held at the 62.5 level by a dam on the rockfill system sustaining a net head of but 29 feet. There is a rock location for the lock. The one essential difference is the greater length of the dam, owing to the width of Gatun Gap. It necessitates an extensive diversion of the Panama Railroad or the use of a ferry between Gatun and some terminal point between Tiger Hill and Obispo. This location gives the largest lockage supply of any Project.

LOCKAGE.

The lockage reserve with this provision depends upon the area and storage capacity of the larger lake which will extend far up the valleys of the Trinidad and Gatuncillo. The area will be over 100 square miles. Reckoning all the factors of minimum water supply, of evaporation, percolation, seepage, and leakage, it is assured that more than 50,000,000 tons may be passed.

Such a tonnage demand is not likely to obtain for a century to come.

PROJECT B′

ELEMENTS

SIX LOCKS, LAKE CHAGRES 33.5, LAKE GATUN 62.5, LAKE BOHIO 97.5, LAKE PANAMA 26.5.

The essential features of Project B′ is the putting of dams at Gatun and Bohio, thus raising Lake Bohio to, say, 97.5 feet. It is an application of the net head principle, by which three dams are used to secure a high level, with a maximum net head of under 40 feet. It represents as well nearly the highest level a canal can be set at and yet utilize the Empty Basin and Divided Channel Control System.

It is clear that this canal is simply a modification of Project B, by which a very large amount of excavation is eliminated and the total is less than under any other scheme.

GATUN DAM.

The net head Gatun Dam is constructed in the same location and on the same plan as the Alternative Gatun Dam of Project B, sustaining the Gatun level of 62.5 feet.

BOHIO DAM.

The net head dam at Bohio sustains Bohio Lake at an elevation of 97.5 feet. Its construction is of the same type.

OTHER ALTERNATIVES OR MODIFICATIONS.

The foregoing constitutes an outline of the dispositions of the three types of the Bates Projects. Lakes Chagres and Panama would be formed if one fixed on levels anywhere down to + 7, although descent below + 20 renders the lakes smaller in area and involves greatly increased quantities, which in turn increases cost of excavation and spoil distribution. If one fixed upon a level below + 10 the Pacific Ocean could be impressed into service as the Feeding Reservoir. All lockage water necessary might be taken in during the last hour of the higher Spring tide.

One could therefore easily make a project for a practicable Mean Sea-Level Waterway with a combined Barrage and Lock near Miraflores, but the enormous amount of excavation required to construct a safe transit channel for the largest ships would run the cost to figures and to duration of execution which are practically prohibitory. Further, the time of transit of a large vessel in a sea-level canal would be longer than in this lock canal, because the vessels would have to proceed slowly and with much caution in a narrow channel for 41½ miles in the former; in the latter they would have many miles of free lake navigation and only a few miles in a waterway, nowhere less than 8,000 sq. ft. in section. The currents of the north and south channels would offset each other, and several hours would be saved by reason of the open lake sections.

CHAPTER VIII.

MISCELLANEOUS DISPOSITIONS.

OIL PIPE LINE.

One of the problems of construction relates to fuel. The saving of more than a million of dollars and vital questions of labor, health and efficiency are involved. Therefore, a well considered policy should be adopted from the outset.

Coal, which seems to be the accepted fuel, is dear and has many special disadvantages in the tropics. The writer strongly advocates the use of crude oil for all canal construction operations, and recommended last year that there be installed an oil pipe across the Isthmus of Panama, connecting the cities of Colon and Panama, and located along the the route of the new canal or railway, with a spur extending to the upper Chagres regulation works at Alhajuela.

ISTHMIAN FUEL SITUATION

High quality steam coal of 14,500 B. T. U. cannot be delivered at Colon alongside wharf for less than $4.75 to $5.00 per ton. It will not be placed on railway cars or barges for distribution along the route for less than $1.00 per ton. The average transportation expense will be at least another dollar, and unloading charges will be fifty cents, making a total cost of about $7.25 per ton.

It is safe to say that coal would not be delivered to consumers at any point, excepting very near Colon, for less than $8.00 per ton. This figure would be very greatly exceeded for places not reached by the railroad, for example along the line to Alhajuela, where the price can mount to $10.00 or $12.00 per ton.

The price of coal can vary from $6.00 at Colon to $13.00 as a maximum in the districts named. Other fuel is not available. Water and electric power will require too much time to develop, and electricity is too experimental in excavating machinery to be considered a factor in the canal construction.

In time, undoubtedly, water power electric plants should and will be installed to operate the locks and sluice gates and for lighting, but even these must have other power ready for emergencies.

Experience in dredging has shown that one cubic yard of material can be removed and distributed by the consumption of about .003 ton of coal with modern apparatus.

Excavating in the dry one cubic yard of material can be removed by the consumption of .001 ton of coal. The distribution in the latter case will require about .001 ton per cubic yard, making .002 of a ton of coal per yard in the dry, for removal and distribution. In addition about .0005 ton per cubic yard should be added for transportation of materials, supplies, etc., and for lighting and heating.

The above quantities become .0025 ton of coal per cubic yard "in the dry," and .0035 ton of coal per cubic yard "in the wet." This is larger than "in the dry" because so much water is necessarily handled in dredging operations.

Taking one ton of coal as equivalent to .625 tons of oil the mean average of excavation half wet and half dry becomes .0019 ton of oil per cubic yard, or, say, .002 at Panama. The moving of 150,000,000 c. y. with attendant operations will, for example, require the consumption of 300,000 tons of oil and 487,500 tons of coal.

Crude oil burnt under a boiler with proper appliances shows an effectiveness by weight of 162.5% of high grade steam coal. One ton of crude oil is equivalent as a steam producer to 1.625 tons of high class steam coal. Using this factor, a ton of oil has a cost value of $6 × 1.625 = $9.75 and $13 × 1.625 = $21.12 in its equivalent to coal; $8.00 per ton will be a fair average price for coal, and this makes an equivalent average price of $13.00 per ton for oil.

The price for oil can and will favorably compete with $6.00 coal at Colon, and more favorably with the prices that will be charged at other points.

The quantity of fuel-oil needed will depend upon the canal project which is finally adopted, and upon the amount, character, methods, and conditions under which excavation is handled. The manifest advantages of oil over any other possible fuel, make it certain that were it installed, no one intent upon saving money, either contractor or Government representative, could fail to utilize it where possible. Oil burning apparatus may be substituted for coal appliances on any machine very cheaply.

The pipe lines should have a delivery capacity of about 200 tons per diem.

Oil can be stored easily and distributed at very small cost. Besides the saving in first price of fuel to the consumers, whether the Government itself or other constructors, there is in addition a very large saving in handling and operation.

In the class of machinery to be used for canal construction these factors will amount to very large items. The use of oil means a very important reduction in the labor force.

It may be also of greatest assistance to sanitation, for it is of prime utility in killing the larvæ of mosquitos, to which the dreaded fevers are at least in a large measure due. It may be used to clear and prevent vegetation along the ditches and drains, and to keep down the rank growth in other locations.

DETAILS OF INSTALLATION.

The route for the pipe line projected is along the grade of the existing Panama Railway. In the section between Bohio and Culebra definite location cannot be fixed until after the new canal line in plan and elevation is permanently established.

The pipe line should be arranged so that it may be tapped at places most convenient for the supply of fuel-oil to plant at work on the canal, and it should be suited to whatever classification or division of work may be followed.

Control and storage tanks, together with the necessary pumping-plant, and installation common to the most modern and improved oil pipe lines, should be erected.

The plan should contemplate the receipt of oil at sea level where large storing tanks to a capacity of 3,000 tons may be installed. This capacity is sufficient to receive the full cargo of an ordinary oil transport. A pumping plant should be provided at this point of sufficient force to discharge this cargo in less than three days. Another pumping plant for supplying oil to the line and maintaining its pressure for distribution should also be installed at the same point. It is anticipated that the average amount of oil delivered to consumers will be at least 3,000 tons per month, which is equal to a full ship cargo.

In order to insure service, additional tanks should be erected at points along the line. Four such tanks may be planned, each having a capacity of 1,000 tons, and a combined capacity of 1,000 tons more than the storage at the receiving end. The pipe line pumping power should be calculated for delivering 100% in excess of the quantities normally wanted, and should be dimensioned so that the sum of the static and friction heads will not exceed 250 pounds per square inch. High pressures occur only on the section of the line between the Bay and the highest point at Culebra, since beyond this the supply under circumstances of normal load may be furnished by gravity.

Two pumps are desirable—one as a reserve to the other, so that a tank ship can be unloaded in case the latter is not provided with its own appliances.

Steam pumps are considered in the estimate, but oil engine driven pumps can be substituted, though at a somewhat greater cost. The advantage in the latter case would be considerable, since good boiler feed water may not be easy to obtain, while the harbor water will be suitable for cooling the oil engines.

In operation the pumps will supply the tanks and line at Kilometer 55, and the rest of the route will be supplied by gravity or nearly so.

A telephone system should be included for facilitating operations. Tanks at Kil. 24 and Kil. 46 will have to be controlled by the gauges and floats and automatic cut-off valves in order to prevent excessive pressure.

The pipe line should be buried or covered where practicable.

The pipes, valves and tanks ought to be coated with asphaltum to prevent their destruction, and all materials should be of the best quality for purposes indicated.

Fifteen valve houses are needed as delivery centers. These houses should be large enough to permit the attendant to have a sleeping and living apartment, so that he may always be found on the premises.

The cost of this installation will be less than $300,000. It will pay large dividends in economy of life, labor and cost.

RAILWAY.

It needs no intimate analysis to decide at the outset that the Panama Railroad should be made and operated to serve the fullest needs of transit commerce and Canal construction.

The permanent line of the Isthmian Railroad must be fitted to the Canal, not the Canal to a railway riveted to a location which would contribute to committing the United States to a sea-level waterway. New railroad work is to be done after and with specific reference to the Plan of Canal adopted, because the detailed location and duty required from construction varies for every project, although in all instances the ultimate main line should be on the east side of the Canal. In two years, by erecting low dykes and barrages across the Chagres and the Rio Grande Rivers, two lakes can be made at the Atlantic and Pacific termini of the canal, navigable for 17¼ miles by the largest ocean vessels afloat. These two lakes will reduce the land width of the Isthmus to 24¼ miles. If a third lake be made at Gatun or Bohio, which can be accomplished in the same time, there will be only *eleven miles* between ocean ships.

The additional tracking of 47 miles of road, widening grades, constructing culverts, bridging the Chagres, much of which work must be altered to accommodate the Canal, and all of which will be unnecessary when the Canal is done, as a single line of railroad will be ample, is superfluous. At the upper ends of the new lakes may be erected temporary docks and terminals which will be necessary in any event for canal construction.

Since some change of location of the Panama Railway is necessary and incident to each different plan, excavation work in respect to this indispensable adjunct is pertinent to the comparison.

The extent in mileage of the railway changes is told by the following table:

DISTANCE IN THE STATUTE MILES.

LENGTH OF PRESENT LINE, COLON TO PANAMA, 47.1 MILES.

	OLD LOCATION.		NEW LOCATION.		
PROJECT	MILES RETAINED	MILES ABANDONED	MILES NEW	MILES TOTAL	REMARKS
Sea Level....	30.5	16.6	17.7	48.2	
30..........	30.5	16.6	17.7	48.2	45 on Bohio hill side.
Comité Technique...	19.7	27.4	28.5	18.2	75 on Bohio hill side.
85..........	19.7	27.4	28.5	48.2	100 on Bohio hill side.
100.. Gatun......	13.2	33.9	57.3	70.5	Gatun Dam entails large extra expense to Ry. or resort to ferry.
130.........	19.7	27.4	28.5	48.2	
Bates A.....	30.5	16.6	17.7	48.2	Raise Present Grade for 13.5 miles
Bates B. (Bohio Dam)	19.7	27.4	28.5	48.2	Raise Present Grade for 13.5 miles
Bates B′.....	13.2	33.9	49.7	62.9	Resort to ferry or large expense for new location around Gatuncillo Swamp. Raise 9 miles.

POLICY AS REGARDS CANAL.

This railroad property should belong wholly to the Government. Its bonds as well as its stock should all be retired by the United States, and the present corporation should cease to exist. As to its $3,000,000 of outstanding bonds, the Government has, in effect, now to pay very high interest charges. Four and one-half per cent. and 6 per cent. interest is paid, while the Government can borrow all the money it may wish at but 2 per cent. per annum. Until the policy of acquiring and retiring these bonds is adopted, one may consider that the road's commercial earnings take care of the interest and sinking fund required and other fixed and operating charges, and that no surplus is turned into the United States Treasury. Such a course is reckoned in the financial computations.

In a wide view, the terminals, equipment, track, etc., should be now improved so as to give the most efficient service to foreign, local and canal traffic, and the recent dividend might well have been applied to this purpose.

As the Government has made its internal canals and water highways free of tolls, so it might make the Panama Railway free to Coasting Trade between our Atlantic and Pacific seaboards and to export and import trade into Atlantic and Pacific ports carried in American vessels. Such a policy would vastly benefit the whole people and especially the American Marine, which needs it. It would be identical in principle with the assumption of Suez Canal dues by several European

Governments. Suez dues work out about one dollar per ton weight, and this rate, with proper plant and equipment, would practically cover the actual cost of transferring cargoes across the Isthmus.

This principle applied at Panama would assure active competition and the carriage of canal supplies at low rates in American vessels.

CHAPTER IX.

SANITATION.

[illegible] a mechanism for the service of commerce. Its bed, [illegible] dykes, its spillways and barrages, its railway, docks

[illegible]

[illegible]

and with a native lower class population, shiftless, negligent and disease-saturated. This Isthmus is the prospective focus of the world's trade. On it are concentrated a large number of the adverse natural and artificial conditions which limit human accomplishment and human life. From the heavens, heat, moisture, calms, "Northers," drenching rains, each vies with the other in insidious drains upon vitality. On the earth the jungles and the marshes fester in fevers, miasma and malaria, while torturing and poisonous insects breed death unbrokenly. Thus is nature entrenched here. Her ways it is beyond human agencies to permanently and naturally reform and change, save through her one self-appointed master.

The royal road is not primarily medical;—a disinfecting, mosquito-netted, nursing road. It is far more fundamental, more drastic, more uncompromising, more eliminative, more cumulative. It is an engineering way; the conquering way of water. Pure water to drink and everybody drinking it, because there is no other procurable, water to carry sewage to a purifying lake or ocean, but, first and chiefest, water *domain* so extended as to limit to the uttermost the existing land area with its inherent and inevitable conditions; this is Panama's one road to redemption.

In the report of the Isthmian Canal Commission made in November, 1901, attention is drawn to the insalubrious environment and the prevalence of fevers on the Isthmus in the following words:—

"Perhaps the greatest difficulty to be encountered in the construction of the Canal will be the procurement of an adequate force of laborers and the preservation of their health and efficiency. In this respect the Panama route has a lugubrious history. The notorious mortality which attended the construction of the Panama Railroad, and later the operations of the Panama Canal Company, has taught a lesson which will not soon be forgotten for that route."

In the first annual report of the second Walker Commission, constituted under the act of June, 1902, statements of similar import recur. Under date of December 1, 1904, is the following:

"Appreciating the importance of taking every possible precaution for the protection of the health of the employes of the Commission on the Isthmus, as well as of the inhabitants of the Canal Zone, the Commission lost no time in organizing a health department. It was fully realized that the reputation of the Isthmus of Panama for unhealthfulness, whether this representation was deserved or not, justified and, in fact, made imperative, the adoption of extreme measures for the prevention and cure of disease. Adequate provision has therefore been made to prevent the introduction of contagion, to wage effective war against the disease-breeding mosquito, and the efficient care of the sick. This has been done not only with due regard to the immediate requirements, but the organization of the department is such that it can be enlarged and expanded as may be required to meet any emergencies."

It is apparent, however, from recent developments that, thorough as may have been the measures taken for sanitation, the Isthmus has not changed its behavior and is still very far from being a region suitable for the white man. The fact that Panama is a tropical country, only 7° north of the Equator, is not reason enough for its history of mortality. The disease and death are due to two main causes:

1st. The mosquito-ridden and miasmatic swamps of the country, which breed fever too rapidly and extensively for science to cope with it by disinfections or by any other measure, short of annihilation of the source.

2nd. The malarially-infected state of human and insect bodies, the unsanitary conditions of the dwellings and towns, and the lack of proper water supply and sewage.

Of these two disease-breeding causes, the sanitary measures now being employed can affect the second only. One may fight mosquitoes, disinfect and isolate infectious cases, erect new houses and hospitals, create water-supply systems, install sewers, pave streets, but all this and more will be required.

A tropical country is not of necessity fever-ridden, but the thousands of buildings all across the Isthmus are built upon ground impregnated and sodden with dormant elements of disease, cultured during years of malsanitation. Refuse has rotted everywhere along the line and been disseminated by the rains. Every form of excavation except from the safe surface of a lake exposes men here to deadly perils. Even living near the sites of old dwellings is dangerous how complete soever may be the surface disinfection. The best practice of medical service and of ordinary engineering can touch but a tithe of the evils. The Isthmus cannot reach the possible maximum of sanitary safety until the low lands and all they hold are drowned utterly. This, it will be shown, is possible only under the new Canal Project herein enclosed.

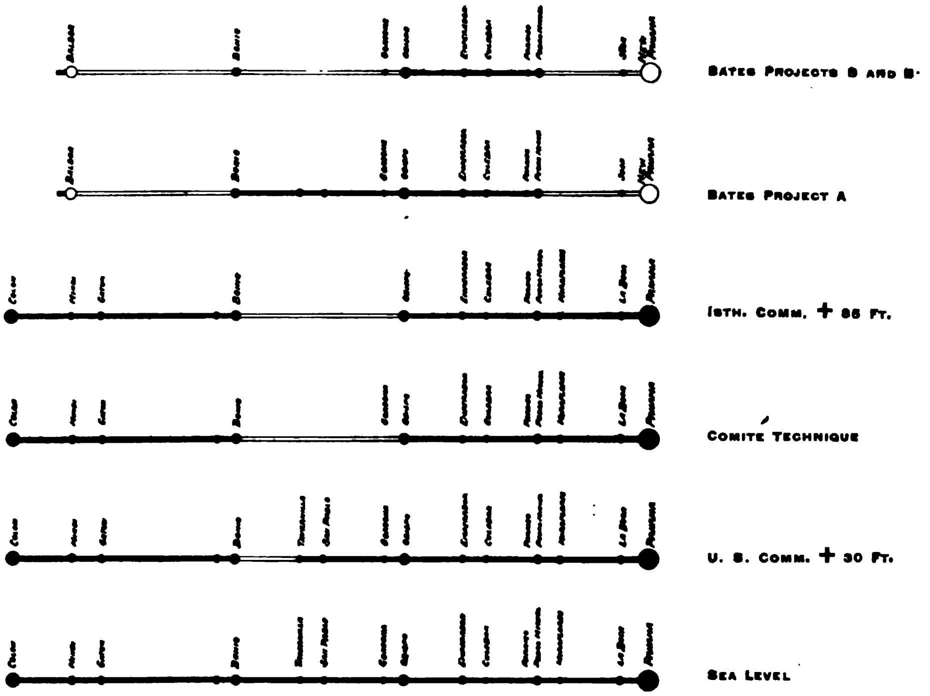
[illegible] is one must deal radically with the present centers of [illegible], the intervening railway stations, and the French [illegible] of them as practicable), and put the population on [illegible]s. The terminal cities should be children of the Canal, [illegible]n. Permanent intervening towns in the valley are [illegible]

[illegible]

[illegible]

With the lake system of Project "A," and yet more with that of Project "B," it becomes feasible and imperative to employ floating plant everywhere, except at the lock and dam sites and on the summit section—the ends of which, however, can also be vigorously attacked by dredges. This is an all-important feature of the new plan, for the most healthful and sanitary, as well as the most economical, plant which can be employed on works of excavation is *floating*, not *land*, plant. And no method of digging the canal can at all compare in wholesomeness with this water system herein advocated.

SANITARY RANK OF VARIOUS PLANS.



White—Healthful Locations.
Black—Unsanitary Locations.

Men afloat live in the shade. They are sheltered from sun and rain. Their work is not disorganized whether there come a shower or a six-day deluge. They can sleep in well-ventilated, mosquito-proof quarters, and can get the full benefit of the water breezes. The quality of men employed upon hydraulic plant is of the most intelligent grade. They are always under better discipline and under closer observation. Drinking water is distilled and chilled aboard. Provisions are kept in cold storage chambers. Meals are regular and ample and diet being provided is under control. Vessels or quarter boats have ideal sewage. It is not and never can be possible to duplicate such favorable conditions ashore in the tropics.

It follows that everywhere on the Isthmus there will be less difficulty with labor, less hazard to life, the more work is done with floating plant. The safest and most extensive employment of such a method is in connection with the Bates' Projects. In a sea-level channel, dredges, and attendant fleets of barges must operate in a low, narrow cut in the midst of the swampy jungle, instead of on an open lake surface.

Colon should disappear and another terminal arise. Panama should survive—cleaned up, sewered, paved and provided with good water, but, after all, only as a suburb of Greater Panama, where the citizens can have a new and better city on the Culebra Reclamation.

COMPARATIVE HEALTH AFLOAT AND ASHORE IN THE TROPICS.

In order to set forth convincingly the comparative health of men afloat and ashore, an analysis of the Reports of the Surgeons General of the U. S. Army and Navy for the past five years is subjoined. The results are strikingly shown by the following table:

TABLE I.

U. S. ARMY.

War Period. Malarial Records of U. S. Army.

REPORT OF YEAR.	NUMBER MEN.	ADMISSION FOR DISEASE.	RATE PER CENT.	MALARIAL RATE PER CENT.	REMARKS.
1898	9.907	18.843	190	42½	Philippines
1899	105.546	229.885	218	71½	All services
1899	64.446	150.949	234	63⅓	Regulars
1899	41.100	78.936	192	48.2	Volunteers
1899	8.082	19.720 E	244	104.7	Volunteers, Cuba
1899	22.922	60.284 E	263	70.5	Regulars, Philippines
1899	26.208	46.388 E	177	36.3	(From Foreign Service) Regulars at home

(E interpolated from data in report.)

TABLE II.

U. S. ARMY.

Showing Percentage of Sickness from Malarial Diseases.

(From Official Reports.)

REPORT YEAR.	WHOLE ARMY.	IN CUBA.	IN PORTO RICO.	IN PHILIPPINES.	IN UNITED STATES.
1898	61.2	192.5	77.2	42.5	53.1
1899	57.4	109.8	45.8	62.4	29.1
1902	43.0	22.6	22.9	51.6	11.3
1903	27.2	——	——	47.1	9.6
1904	20.1	11.1		45.9	6.08
1891 to 1900	40.8	7.3			

The reports of 1902-3-4 relate to periods when active measures against the mosquito became universal at army posts. 1898 and 1899 to a war period when men were much exposed and sanitary measures were more difficult.

TABLE III.

U. S. NAVY.

MALARIAL RECORD.

GENERAL.

YEAR.	AFLOAT.	CASES.	PER CENT.	ASHORE.	CASES.	PER CENT.	RATIO.
1900	15,982	1,103		3,684	248		
1901	16,501	601		5,980	448		
1902	18,352	581		7,152	590		
1903	22,596	910		7,653	902		
1904	27,556	661		7,843	505		
	100,987	3.856	3.84	32,312	2,693	8.34	2⅙ to 1

TABLE IV.

PHILIPPINES (Asiatic Station).

REPORT YEAR.	AFLOAT.	CASES.	PER CENT.	ASHORE.	FEVER CASES.	PER CENT.	RATIO.
1900	4,652	339		413	300		
1901	5,557	278		115 492	90 270		
1902	6,312	225		405	268		
1903				515	248		
	16,521	842	5.1	1,940	1,176	60.6	12 to 1

TABLE V.

GRAPHIC DIAGRAM OF MALARIAL REPORTS.

ALL NAVAL SERVICES.

YEAR	NO.	M.D.	PER CENT.
1900	20.113	943	4.7
1901	23.756	983	4.14
1902	26.101	1,112	4.2
1903	30.249	1,408	4.6
1904	36.535	1,221	3.3
	136.754	5,667	4.14

TABLE VI.

RECORD OF FORCE ASHORE.

ISTHMUS OF PANAMA.

YEAR	NO.	M.D.	PER CENT.	PLACE	FORCE
1902	138	110	80	Emperador	Marines
	58	182	314	Panama	"
1904	487	294	60	Emperador	"
	683	586			
1904	102	70	70	Real Maria	"Boston"
1903–4	40	28	70	El Real on Rio Bayamo	"Wyoming"

TABLE VII.

DEATH RATE.

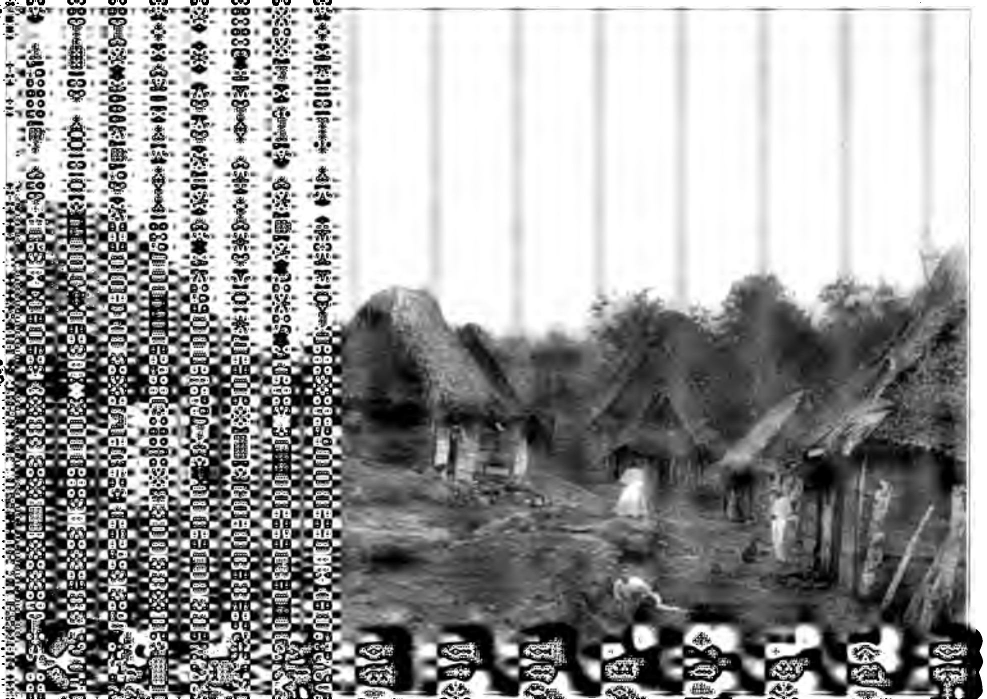
ARMY AND NAVY.

REPORT OF YEAR	ARMY	NAVY		GENERAL, INCLUDING HOSPITAL	REMARKS .6
		AFLOAT	ASHORE		
1899	27.99	3.74	5.67	7.21	
1900	18.43	3.50	7.33	7.35	
1901	19.94	4.66		8.88	Decade 11.91 Army
1902	13.94	3.21	4.48	6.18	
1903	15.49				
1904	9.30			0.01	
1894–1902	6.69			6.78	

Tables Nos. I, II, IV and VI show the unfailing incapacitating effects of environment upon white men ashore in tropical climates everywhere, in Cuba, Porto Rico, the Philippines and pre-eminently in Panama.

[illegible] in military service the death rate of men ashore is [illegible] afloat.

[illegible] prove that in the navy, generalizing throughout all [illegible] shore duty is 2½ times as liable to malaria as his [illegible] record to a tropical station, like the Philippines, [illegible] the chance of the shore man. At Panama the land [illegible] to 60 times as certain to pay the malarial disease [illegible], furthermore, malaria does not stand alone, nor is [illegible]



[illegible]

[illegible]

of de Lesseps' splendid ten-year struggle, each in turn has charged the deadly, silent forces of that Isthmus like desperate Balaklava invincibles, only recalling their luckless story. It is ever the same tale. Some one has blundered. In the new Panama history the disaster promises to be no less poignant unless some one does "reason why."

A recent official report states that 50 per cent. of the hospital cases at Colon are malarial, that the death rate is ninety per thousand. In the Army (Table VII), for the decade 1890–1900 the ratio is 11.91 per thousand, in the Navy about 7. Colon's population is mostly men and a normal death rate should not be over one-sixth of what it is.

The Marine Guard with care and under discipline (Table VI) stayed out their year at Emperador, the best place on the route. Had they not been in the United Service no one will believe that their organization could have been held intact when 60 to 80 per cent. had to receive hospital treatment for Chagres fever. Had they been canal laborers, working 8 to 10 hours per day in sun and rain, with shovel or drill, the record would have been much higher.

The experiences of the forces landed at other points of this littoral, tabulated from the "Boston" and "Wyoming" in Table VI, show that fever broods over the whole Isthmus.

At Camp Dewey on Culebra Island, West Indies, the detailed reports show that 275 men on the "Panther" anchored off shore had one-sixth as many malarial cases as an equal number of men in camp only a thousand yards away. When the men were taken aboard they soon approximated their ship's rate.

Convincing and impressive and indisputable as are these evidences, still such tables cannot disclose the full story. Soldiers, sailors and marines are under a shore discipline which cannot be applied to labor on public works except when afloat. The men of naval and military forces are under a medical surveillance which anticipates and wards off illness. The shore man feels ill or ailing, he lays off, he moves away, he is sick at home, he is dropped from the pay-roll; the soldier or the sailor is hustled into the hospital. The land man usually deprecates the hospital, and if he can sails away north. So it results that the medical story of the laboring man ashore is necessarily a worse record, worse for the man and worse for the employer, than the official government reports reveal.

Every employee on the Panama Canal knows that once impregnated with Chagres fever it is liable to recur again and again. Only afloat or in a different climate may the victim overtake his lost health.

The Culebra Cut, the Locks and Dams and Terminal Works must be mostly executed by land plant, and here is the field for the best that medical and sanitary service can do. The lakes will enable such efforts to be concentrated at the critical points and will assist them more than any other factor.

The table exhibit does demonstrate beyond question the fact that in a fever infested country the man afloat has from 6 to 60 times the chance of immunity from malarial diseases which the man ashore possesses. It drives home the fundamental truth that the way to health and accomplishment at the Isthmus of Panama is the way of water and water should begin its wholesale, beneficent work with the least delay. After a century's waiting and hoping the canal should not be so built that for all nations, through all times, to the toll of the passage must be added the toll of the Chagres death.

Laborers will be wanted for Panama. The securing and the keeping of them has thus far not proved either easy or inexpensive. Governments considering the recruiting of their citizens must be satisfied as to their chances for survival. The days of the Corvée are over. The interests and rights of the humbler classes which furnish the substantial bone and sinew will not be ignored either by themselves or their rulers. These will all weigh in the balance the sanitary situation at Panama. Here in the very outset the United States will be brought before the bar of National humanity. Should it offer a sea level or any other scheme which inherently recks nothing of the needless sacrifice of life during construction, it is certain that foreign governments will soon reach the decision already impressively expressed in the absence of American labor. The grim legend of a man laid away under every tie of the Panama railroad has a trick of lingering, and the French cemeteries a way of resurrecting in men's memories. The experience of a whole canal enterprise halted openly in the face of the world till some belated provision can be made for defending health is a vivid object lesson. Labor is thinking and it is watching. When the authorities act finally it were wise that they choose well.

CHAPTER X.

[illegible] AVIGATION CONDITIONS.

[illegible] ars which will follow the adoption of a definite canal [illegible] rn will be with construction and its attendant problems. [illegible] ts future of centuries, efficiency for navigation will be [illegible]

[illegible]

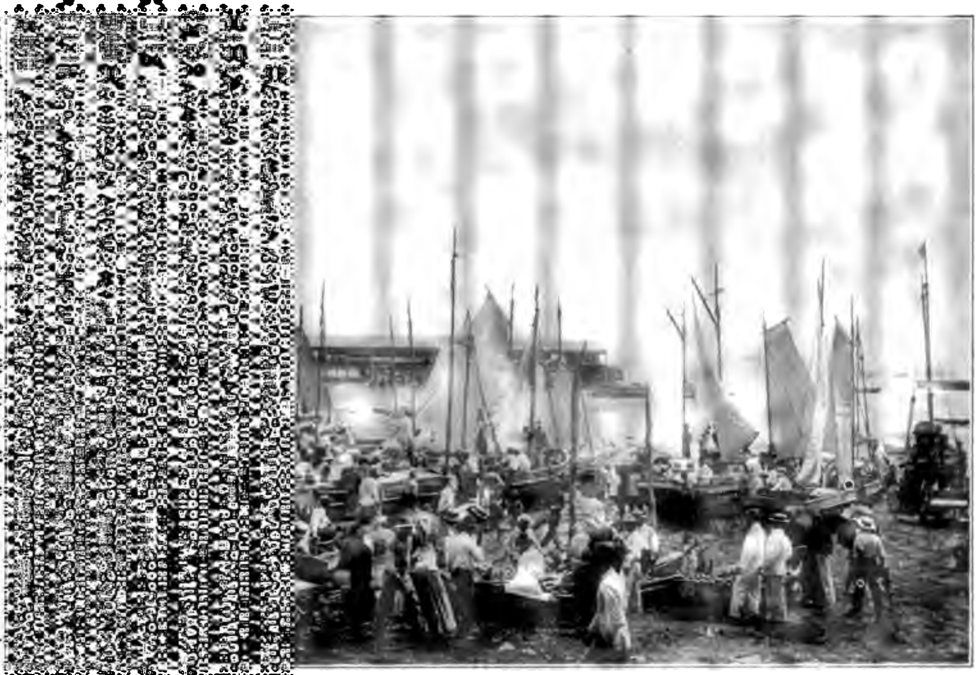
[illegible]

From the ocean the captain would steer a straight course up a wide buoyed channel, toward the city of Balboa on Jaramillo Hill. The ship would pass between the breakwater heads and through the outer saltwater harbor to the assigned mooring buoys in the Reception Basin just below the Terminal Lock. Here quarantine officials would visit her. After passing inspection, an officer would go ashore, as is customary, to receive orders and get the dispatches, and the Canal Inspector would come aboard to measure the tonnage. Meanwhile the vessel might be docked in the salt water harbor, or pass the terminal lock and come to the wharf or buoy in the inner fresh water harbor on Lake Chagres. At the terminals, a stay of several hours is made in such canals, coal and supplies are taken on, passengers are transferred, the vessel pays the passage dues, and various routine business is transacted. During this necessary stay in port, the terminal lock would be passed, so the time spent in thus doing does not count against the time of actual canal transit. Every captain appreciates the supreme advantage to his voyage of a halt in fresh water which will remove barnacles or kill the teredo. It is perfectly apparent, and any practical navigator reviewing a chart, will agree that these arrangements are the safest from a sailor's standpoint that could be devised. The broad entrance to Limon Bay, the wide channel without a curve, leading into an outer harbor in the head of the bay engirdled by hills and protected by a strong breakwater, the entry to the Canal lock from the Reception Basin still further in and nestled between Quebrancha and Jaramillo Hills and then the passage into the fresh water harbor behind them,—all these combine into dispositions which make the entrance easy, safe in any weather and perfect in every detail.

On the other hand the navigator will know also that in any plan which seeks to preserve Colon as the terminal city the breakwater would have to extend across the mouth of Limon Bay, enclosing so unnecessarily large an area that protection would be inadequate. He will appreciate the dangers of the reverse curves of the old canal entrance. And particularly, he will note the variable and undue currents that at various times could not but be set up in any open sea-level canal entrance, due to tides, rains and wind on both sides of the Isthmus. A merchant captain or a naval commander will, therefore, not wish to exchange the advantages of fresh and salt water harbors, straight, safe entries and all that go with the designed harbors of Balboa and Panama, for the disadvantages attending the old locations.

On receiving dispatch, the ship, leaving the fresh water harbor on Lake Chagres, would steam, under Project A, for 10.4 nautical miles up a buoy-marked *Lake* channel, at a rate somewhat over twice that which could be possibly allowed in any of the constricted channels of former plans. There would be no freshet-made silt bars to ground on, no imminent banks to swerve against, no [illegible] disturb steering. If Project B or B′ were adopted, there [illegible] at Gatun, leading into a higher lake, but open navigation [illegible] likewise as far as Bohio.

[illegible] the long sweep of curves to avoid the spur of the coastal [illegible] projects adopt, the vessel may pass by a new alignment [illegible] Bohio. This shortens the distance by 1.2 sea miles, and [illegible] curvature, between Gatun and Bohio.



[illegible] FRONT OF PANAMA. ISLANDS OF NAOS AND PERICO IN BACKGROUND.

[illegible] nel [illegible] and [illegible] an [illegible] ling

[illegible] the [illegible] n a [illegible] ld, [illegible]

In Project B, the Gatun lake would extend as far as Obispo. In Project "B′" a higher lake would be entered at Bohio, taking the ship to the same point. The speed which could be gained in this lake navigation would nearly counterbalance the lock delay, and would bring the time of transit very close to that under Project "A." The Obispo Triangle, at a higher level than in Project "A," would be passed at the upper end of the lake. Then would come a 9 mile reach of canal, all the real canal which would exist on the Isthmus, the Pedro Miguel locks would be traversed and Lake Panama would be entered.

In every other scheme, in place of steaming rapidly through Lake Chagres, the vessel must in this first section crawl at four or five miles an hour, through the fateful sea-level marshes. The death fee must for all ages be paid to this swamp passage. If the canal were on the high central lake principle, that of the Comité Technique or Commission of 1901, there would be passed next on the route, between Bohio and Miraflores, five locks. If it were sea-level, the ship would be below the swamp area, at the bottom of a narrow gorge, proceeding slowly and warily to avoid hitting the canal banks. At Obispo the passengers could look up at the massive Gamboa Dam, monstrous and misshapen, winding across the valley like a snake and towering in menace 150 feet above them. They would have further the quieting consciousness that if part of the "probable rock varying from soft limestone to medium hard basalt" forming the spillway tunnel were to cave in during the flood period, a lake 200 feet deep might be let loose over their heads.

Through the Pacific coastal region they could contemplate more swamps and combat anew the mosquitos and malaria and finally come to anchor in the poor La Boca roadstead.

The vessel under the author's plan would in this last section have steamed rapidly through a lake—Lake Panama—and would moor in the fresh water harbor there near the U. S. Naval Station. The captain would get his final sailing orders and take on freight for the trip, and the passengers would tour the regenerated city while the vessel was being locked into the great ocean harbor of Panama. Receiving them aboard again, she would then steer out past the Pacific quays, through the passage between Naos and Perico Islands which head the giant enclosing Culebra rock breakwaters and sail away into the Pacific Ocean, having spent from four to six hours less in the canal than under any other project.

SAVING OF LENGTH.

NAUTICAL MILES.

Under the location of all the other projects, both sea-level and locked, the length of canal between La Boca Pier and the mouth of the Mindi is approximately 35M., 1,130F. Under the Bates design, the length of Canal between the terminal locks is 33M, 5,126F. with the Gatun cut-off.

Under the location of all the other projects the total length, including harbor and approach, is 46M, 578F.

Under the Bates design the total length including harbor and approach, is 41 sea M, 5,545F. with the Gatun cut-off.

The saving under the new plan is 4 sea M., 1,113F.

COMPARATIVE TIMES OF TRANSIT

One of the vital tests of the merits of any plan for the Isthmian waterway is the duration of transit. It is axiomatic that the design which creates a canal with conditions of navigation which take a large ship the longest time to negotiate has its utility largely discounted as against a canal which takes the shortest time to traverse.

CALCULATIONS RE TRANSIT TIMES.

In calculating these times, it is assumed that each canal will start at Mindi rather than at Christobal, the old entrance near Colon. The distance to be traversed is taken to be the same for each project, with the following exception: Projects A, B and B′ have the benefit of the Gatun Cut-off, which entails little expense for these plans and a very large expense for the others. These projects are calculated for the shortened and straightened Pacific alignment to the Ancon-Sosa Lock, the others to La Boca Pier.

It is assumed for all projects that in the channel tangents the allowable speed for the largest vessels is 4.5 miles per hour, and on curves 4 miles per hour. In the open reaches of Lake Navigation a speed for the largest vessels of 9.5 miles an hour is used.

The time of passing terminal locks is not counted as affecting the total passage period. This course is entirely justified by the universal custom that ships spend several hours at both termini of such a canal, during which necessary period end locks may be passed without any real loss of time. The actual practices of navigators in passing through Isthmian canals after a long voyage must be considered. The time is, therefore, reckoned between the actual dispatching stations without reference to the movements of ships in port. Under proposals A, B and B′, it is shown that a daylight trip from end to end is entirely practicable and that no others offer this advantage.

PROJECT A

	DIST. IN STAT. MI.	SPEED STAT. M.P.M.	TIME HRS.
Lake Chagres	9.861	9.5	1.038
Channel Tangents	11.600	4.5	2.577
" Curves	10.99	4.	2.747
Lake Panama	5.248	9.5	.552
	37.699		6.914

Time lost in speeding up and slowing down at Mindi and Sosa	.158
Transit Time without meetings	
Channel % of length 60%	
Lake " " " 40%	
Meetings in Transit	1.380
Total Time	8.452

PROJECT B.

	DIST. IN STAT. MI.	SPEED STAT. M.P.M.	TIME HRS.
Lake Chagres	2.371	9.5	.249
Lake Gatun-Bohio	19.559	9.5	2.059
Channel Tangents	5.849	4.5	1.299
" Curves	4.641	4.	1.160
Lake Panama	5.248	9.5	.552
	37.668		5.319

Time lost in acceleration and retardation at Mindi and Sosa	.158
Lock at Gatun	1.067
Retardation at Gamboa	.022
Lock at Pedro Miguel	1.037
Transit time without meetings	
Channel % of total length 28.1	
Lakes " " " " 71.9	
Meetings in Transit	.61
" at Locks	.68
Total Time	8.933

PROJECT B′.

	DIST. IN STAT. MI.	SPEED STAT. M.P.M.	TIME HRS.
Lake Chagres	2.371	9.5	.249
Lake Gatun	7.490	9.5	.789
Lake Bohio	13.055	9.5	1,374
Channel Tangent	5.089	4.5	1.131
" Curves	4.436	4.	1.109
Lake Panama	5.248	9.5	.552
	37.689		5.204

Time lost during acceleration and retardation at Mindi and Sosa	.158
Gatun Lock	1.067
Bohio Lock	1.127
Retardation at Gamboa	.022
Double Lock at Pedro Miguel	1.786
Channel % of total length 25.3	
Lakes " " " " 74.7	
Meetings in Transit	.92
" at Locks	.36
Total Time	10.644

SEA LEVEL.

	DIST. IN STAT. MI.	SPEED STAT. MI. HR.	TIME MIN.
Channel Tangents	18.860	4.5	4.191
" Curves	20.423	4.0	5.106
	39.283		9.297

Time lost during acceleration and retardation at Mindi and La Boca	.075
Tide Lock at Miraflores	.693
Transit time without meetings	
Meetings in Transit	2.15
" at Locks	.18
	12.395

COMITÉ TECHNIQUE.

	DIST. IN STAT. MI.	SPEED STAT. MI. HR.	TIME MIN.
Channel Tangents	12.963	4.5	2.880
" Curves	13.131	4.0	3.283
Lake Bohio	13.187	9.5	1.388
	39.281		7.551
Time lost during acceleration and retardation at Mindi and La Boca			.075
Double Lock at Bohio			1.690
Retardation at Gamboa			.022
Double Lock at Pedro Miguel			1.588
Side Lock at Miraflores			.565
Transit time without meetings			
Channel % of total length 66.43			
Lakes " " " 33.57			
Meetings in Transit			1.55
" at Locks			.35
			13.391

COMMISSION 1901.

	DIST. IN STAT. MI.	SPEED STAT. MI. HR.	TIME HRS.
Channel Tangents	12.963	4.5	2.880
" Curves	13.131	4.0	3.283
Lake Bohio	13.187	9.5	1.388
	39.281		7.551
Time lost during acceleration and retardation at Mindi and La Boca			0.75
Double Lock at Bohio			1.926
Retardation at Gamboa			.022
Double Lock at Pedro Miguel			1.823
Tide Lock at Miraflores			.565
Transit time without meetings			
Channel % of total length 66.43			
Lakes " " " " 33.57			
Meetings in Transit			1.55
" at Locks			.39
Total Time			13.902

SUMMARY.

COMPARATIVE TABLE OF TRANSIT TIMES—IN HOURS.

	PROJECT A	B	B′	SEA LEVEL	COMITÉ TECH.	ISTHMIAN COM.
M. Lakes	1.590	2.860	2.964	......	1.388	1.388
M. Channel	5.324	2.459	2.240	9.297	6.163	6.163
Speeding up and down.	.158	.158	.158	.075	.075	.075
Meetings in Transit	1.380	.61	.920	2.150	1.550	1.550
" at Locks	......	.18	.360	.180	.350	.39
Gatun Lock	......	1.067	1.067	......	......	......
Pedro Miguel Lock	......	1.037	1.786	......	1.588	1.823
Gamboa	......	.022	.022	......	.022	.022
Bohio Lock	......	......	1.127	......	1.690	1.926
Miraflores Lock	......	......	......	.693	.565	.565
Total Transit Time. Hrs.	8.452	8.893	10.644	12.395	13.391	13.902
Average Speed in Waterway	5.46	7.08	7.25	4.23	5.20	5.20

The above calculations are based upon speed in statute miles, per hour, but if the allowable speeds be taken in knots, per hour, and the same figures be employed, the relative superiority of A, B and B will work out still more impressively.

The case is proved that the transit times of the projects of the writer are many hours shorter than those of any other designed canal.

COMPARATIVE ALIGNMENT.

STATUTE MILES.

SMALL FACED TYPE OLD COLON LOCATION.
FULL FACED TYPE NEW LIMON BAY LINE.

PROJECT	TOTAL CURVATURE DEGREES	LENGTH OF CURVES	LENGTH OF TANGENT	LENGTH OF CANAL	DEGREES OF CURVATURE AFFECTING NAVIGATION	LENGTH
U. S. + 85	756° 54′	22.868 M	30.314 M	53.082 M	507° 16′	15.576 M
Commission 1901	**671° 42′**	**21.612**	**30.321**	**51.933**	**422° 04′**	**14.320**
Comite Technique	756° 54′	22.868 M	30.214 M	53.082 M	511° 34′	15.656 M
+61.5	**671° 42′**	**21.612**	**30.321**	**51.933**	**426° 22′**	**14.400**
Lindon W. Bates Project A +27	**532° 14′**	**15.744** M	**32.521** M	**48.265** M	**413° 43′**	**12.173** M
B { 33.5 62 Gatun Cut-Off 27	**532° 14′**	**15.744** M	**32.521** M	**48.265** M	**184° 35′**	**5.251** M
B′ { 33.5 62 Gatun Cut-Off. 97 27 +30	**532° 14′**	**15.744** M	**32.541** M	**48.265** M	**167° 0′**	**4.680** M
+30	756° 54′ **671° 42′**	22.868 M **21.612**	30.214 M **30.321**	53.082 M **51.933**	621° 38′ **536° 26′**	18.697 M **17.341**
+100 Gatun	756° 54′ **671° 42′**	22.868 M **21.612**	30.214 M **30.321**	53.082 M **51.933**	349° 05′ **263° 53′**	10.195 M **8.939**
+130 French	756° 54′ **671° 42′**	22.868 M **21.612**	30.214 M **30.321**	53.082 M **51.933**	511° 34′ **426° 22′**	15.656 M **14.400**
Sea Level	756° 54′ **671° 42′**	22.868 M **21.612**	30.214 M **30.321**	53.082 M **51.933**	756° 54′ **671° 42′**	22.868 M **21.612**

The foregoing tabulation evidences that under Projects A, B and B′ :

1st. The length of the canal with its harbor approaches is the shortest by at least 4.817 miles.

2d. That the aggregate length of tangents or straight courses is greatest by at least 1.893 miles.

3d. That the total curvature is from 139°28″ to 224°40′ less and the length of the curved courses is from 5.868 to 7.124 miles shorter.

4th. That by reason of the series of lakes the curvature affecting navigation in degrees and in length is markedly least under the Bates system.

CHAPTER XI.

FINANCES.

STANDARDS OF PERMISSIBLE EXPENDITURE.

In such a world work as the Panama Canal it is the duty of the engineer to point the way to the best canal. It rests with others to decide whether or no the price for it shall be paid. It is taken as primary and fundamental that the American people wish and are willing to pay for the best canal. On this basis the plans herein described and advocated were made. In this conviction the various dispositions were developed. But, having presented the best that can be offered, it is essential to count the cost with respect to the standards of allowable expenditure. These may be said to be two—the amount fixed by the United States Congress and that calculable as the canal's value when measured by its practical business utility.

AUTHORIZED EXPENDITURE.

After having thoroughly considered the matter in all its bearings, the legislative branch of the American Government formally dedicated to a Canal at Panama a certain sum. Their judgment as to the future utility of the Panama Canal was recorded in the sum voted for its accomplishment, since, by the terms of the law, the President was directed to seek another location in the event of the vendors requiring too high a price. The sum therefore which the Congress of the United States held as the limit of justifiable expenditure is of great significance. Until this action is cancelled by subsequent legislation, the amount is fixed and not to be exceeded.

The Spooner Act, approved June 28th, 1902, provides as follows for the construction of an Isthmian Canal:

> " Section 3. That when the President shall have arranged to secure a satisfactory title to the property of the Panama Canal Company, as provided in section one hereof, and shall have obtained by treaty control of the necessary territory from the Republic of Columbia, as provided in section two hereof, he is authorized to pay for the property of the New Panama Canal Company forty millions of dollars, and to the Republic of Columbia such sums as shall have been agreed upon, and a sum sufficient for both said purposes is hereby appropriated, out of any money in the Treasury not otherwise appropriated, to be paid on warrant or warrants drawn by the President."

> "Section 5. That the sum of ten million dollars is hereby appropriated out of any money in the Treasury not otherwise appropriated, toward the project herein contemplated by either route so selected."
>
> "Appropriations therefor shall from time to time be hereafter made, not to exceed in the aggregate the additional sum of one hundred and thirty-five millions of dollars, should the Panama route be adopted."

The authorized cost of an Isthmian Canal may be tabulated as follows:

AUTHORIZED CANAL COST.

New Panama Canal Co., purchase	$40,000,000
Zone Strip purchase	10,000,000
Annuity to Panama beginning in 1912	250,000
Construction	145,000,000

APPROPRIATIONS.

Spooner Act 2 per cent bonds	$130,000,000
Commission Appropriation	10,000,000
Authorized but unappropriated	5,000,000

THE CANAL AS A BUSINESS INVESTMENT.

The above then offers one most important criterion of allowable expense. A second is its economic value as measured by practical utility. The natural limit of permissible expenditure from the broadest view-point, is the use the Canal will be to society as measured against the sacrifice entailed for constructing it. The closest practical standards to define this are the interrelations which exist between the cost of the design definitely adopted and the Canal's future business and profit as a national enterprise.

Since the Panama Canal is to be used as a highway for the shipping of the world, from which a net tonnage toll is to be collected for each passage, it follows that this work may well be considered in its business aspect and a forecast should be made as to its probable outcome as an enterprise with the federal government as an investor. So regarded, there are three fundamental elements to be considered: Capital Investment, Operating Cost, and Earnings.

The variable factor in the Capital, Construction Cost, has been given by the Commissions. For the 85-foot Canal, as planned, it was officially given as $144,222,358. This sum will be taken as a basis. The constant factors of capitalization are the $40,000,000 paid to the New Canal Company, the $10,000,000 paid for the Canal Zone, $3,000,000 representing Panama Railroad Bonds and the amounts calculated for deficits in the early years of operation.

EARNINGS.

The second factor, earnings, may in the long run be best estimated from the history of other canals. For purposes of reference the tonnage carried by the leading ship canals is here given:

THE SUEZ CANAL.

YEARS	VESSELS	NET TONNAGE	TRANSIT RECEIPTS		MEAN NET TONNAGE PER VESSEL
	Number	*Tons*	*Fr.*	*C.*	*Tons*
1869	10	6,576.00	54,400	80	657
1870	486	436,609.37	5,159,327	22	898
1871	765	761,467.05	8,993,732	87	995
1872	1,082	1,160,743.54	16,407,591	42	1,071
1873	1,173	1,367,767.82	22,897,319	18	1,166
1874	1,264	1,631,650.14	24,859,383	00	1,290
1875	1,494	2,009,984.09	28,886,302	27	1,345
1876	1,457	2,096,771.61	29,974,998	74	1,439
1877	1,663	2,355,447.69	32,774,344	22	1,416
1878	1,593	2,269,678.31	31,098,229	18	1,425
1879	1,477	2,263,332.19	29,686,060	81	1,532
1880	2,026	3,057,421.88	39,840,487	64	1,509
1881	2,727	4,136,779.77	51,274,352	95	1,517
1882	3,198	5,074,808.88	60,545,882	08	1,586
1883	3,307	5,775,861.79	65,847,812	16	1,746
1884	3,284	5,871,500.92	62,378,115	54	1,787
1885	3,624	6,335,752.98	62,207,439	21	1,748
1886	3,100	5,767,655.84	56,527,390	58	1,860
1887	3,137	5,903,024.09	57,862,370	71	1,881
1888	3,440	6,640,834.44	64,832,273	20	1,930
1889	3,425	6,783,187.12	66,167,579	14	1,951
1890	3,389	6,890,094.41	66,984,000	22	2,033
1891	3,207	8,698,777.36	83,422,101	24	2,067
1892	3,559	7,712,028.61	74,452,436	03	2,166
1893	3,441	7,659,068.10	70,667,361	43	2,292
1894	3,352	8,039,175.27	73,776,827	68	2,398
1895	3,434	8,448,383.01	78,103,717	56	2,460
1896	3,409	8,560,283.60	79,569,994	31	2,511
1897	2,986	7,899,373.84	72,830,545	43	2,645
1898	3,503	9,238,603.38	85,294,769	88	2,637
1899	3,607	9,895,630.04	91,318,772	07	2,743
1900	3,441	9,738,152.18	90,623,608	08	2,830
1901	3,699	10,823,840.00	100,386,397	00	2,926
1902	3,708	11,248,413.00	103,720,020	00	3,034
1903	3,761	11,907,288 00	103,620,268	00	3,166

ST. MARY'S FALLS CANAL.

BY DECADES.

YEAR	TONS	YEAR	TONS	YEAR	TONS
1855	106,296	1865	409,062	1875	1,259,534
1856	101,458	1866	458,530	1876	1,541,676
1857	180,820	1867	556,899	1877	1,439,216
1858	219,819	1868	432,563	1878	1,667,136
1859	352,642	1869	524,885	1879	1,677,071
1860	403,657	1870	690,826	1880	1,734,890
1861	276,639	1871	752,101	1881	2,092,757
1862	359,612	1872	914,735	1882	2,468,088
1863	507,434	1873	1,204,446	1883	2,042,259
1864	571,438	1874	1,070,857	1884	2,997,837
	3,079,815		7,014,904		19,920,464

YEAR	TONS	YEAR	TONS
1885	3,035,937	1895	16,806,781
1886	4,219,397	1896	17,249,418
1887	4,897,598	1897	17,619,933
1888	5,130,659	1898	18,622,754
1889	7,221,935	1899	21,958,347
1890	8,454,435	1900	22,315,834
1891	8,400,685	1901	24,626,976
1892	10,647,203	1902	31,955,582
1893	8,949,754	1903	27,736,444
1894	13,110,366	1904	24,364,138
	74,067,969		223,256,207

KIEL CANAL.

YEAR	TONS
1896	1,505,983 (July 1, '95 to June 30, '96)
1897	1,848,458
1898	2,469,795
1899	3,117,840
1900	3,488,767
1901	4,282,094
1902	4,285,301
1903	4,573,834
1904	4,990,287
	30,562,359

MANCHESTER
SHIP CANAL.

YEAR	TONS
1894	925,659
1895	1,358,875
1896	1,826,237
1897	2,065,815
1898	2,505,585
1899	2,778,108
1900	3,060,516

For the shorter period which is more germane to this discussion, the figures reached by the Commission of 1901 are apparently efficiently derived, and furnish a good working basis. Their estimate of 1914 tonnage was 6,843,805 tons. With the decade increment of 25.1 per cent., the available tonnage in 1917 will amount to 7,279,000 net tons, all of which at this time, it is assumed, will pass through the Canal. The tonnage for 1915-16, which represents the beginning of operation, will naturally be less. The actual increase in traffic resulting from the opening of the Canal is taken to begin in 1917.

The Commission Report of 1901 adopted 62½ per cent. as rate of tonnage increase for the first decade (after beginning of traffic) and derived this by taking 50 per cent. of the tonnage increase of the Suez Canal from 1880 to 1890.

In 1880 the total net tonnage of the Suez Canal was about 3,000,000 tons, but the Panama Canal (it is considered) will begin operation in 1917 with the above 7,000,000 tons, and for this reason the decade 1893-1903 of Suez operation, which begins with the 7,000,000 tons, provides a better analogy as to character and quantity of traffic than the 1880-90 decade. The 1893-1903 decade shows an average increment of 45 per cent. beginning with 7,645,000 tons, and this figure is used for the 1917-1927 decade of Panama Canal.

The Suez and Panama Canals will also be competitors for a large amount of tonnage and this condition may reduce the above rate of tonnage increase. At the accepted rate of $1.00 per net ton the earnings become

1915 (assumed)	$1,000,000
1916 (assumed)	5,000,000
1917 (from above discussion)	7,279,000

OPERATING EXPENSES.

The third factor, Operating Expenses, is estimated at $2,000,000 per annum. In this item is included the $250,000 a year due to the Republic of Panama after 1912. So that the canal as a business investment may be reduced to a definite conception by the folowing process:

FIRST COST OF CANAL.

Construction	$144,222,358
Purchase P. C. Co	40,000,000
Purchase Zone Strip	10,000,000
Purchase Outstanding Ry. Bonds	3,000,000
Total Cost (Round)	$197,000,000

CAPITAL REQUIRED.

Total Cost	$197,000,000
Interest 10 years Const. period 2 per cent. 10 years, $50,000,000	10,000,000
2 per cent. 5 years, $147,000,000	14,700,000
Deficit operation (1915-1617)	12,000,000
Total	$233,700,000

FIXED CHARGES—PER YEAR.

$233,700,000. Capital to be provided by issuance of 2 per cent. bonds or use of Treasury Surplus on which at least 2 per cent. should be calculated. Interest at 2 per cent.		$4,674,000	
Sinking Fund and Extraordinary Contingencies ¾ per cent.		1,752,750	

OPERATION.

By Report of Commission 1901		$2,000,000	
Total			$8,426,750
Deficit 1915	$7,426,750		
1916	3,426,750		
1917	1,147,750		
Provided for in Capital		$12,001,250	

FOR 1918, FIRST YEAR OF FULL OPERATION.

With 45 per cent. per decade increase in traffic,

The Income becomes	$7,606,555	
Total Operating Expenses	8,426,750	
Deficit		$820,195

Time, until total operating expenses will equal income at 45 per cent. decade rate beginning 1917, is 2.5 years from 1918 or 5.5 years after opening of Canal.

GOVERNMENT FINANCING METHODS.

For government property, however, the point of view is in certain respects different. Interest, for instance, is not a factor. With the Irrigation Act as a precedent, it is assumed that the United States Treasury will provide funds for starting the exploitation, will meet all deficits (such as will result from the first and second year of operation) and will receive all surplus above operating expenses, debiting and crediting the same to the Canal account without any interest charges whatever. It is to be assumed that all other expenditures will, like the $50,000,000 already paid for Panama Canal Co.'s interest and for the zone strip, come out of the Treasury, and against them no interest charges will be considered. The fixed charges of the undertaking become, by this system, the interest on the bonds issued as above described, plus the operation costs which have been stated at $2,000,000, and which will be figured the same for any project.

Nevertheless the business estimate gives a valuable mode of conceiving the relative value of the Canal, because the standard is that by which all private enterprises are measured and weighed.

The most usual and obvious factors have been used in making this analysis. The revenue from tonnage toll at $1.00 per net ton is the only source of income considered, and this is a fair position to take. Since the fixed charges and operating expenses will remain constant for the scope of these calculations, regardless of the tonnage passing through the Canal, any increase or decrease in the toll per net ton affects in direct proportion the amount of annual earnings and therefore the amount of the surplus or deficit, and finally the amount of capital that can be advisedly expended in the undertaking. For many reasons such an increase is not desirable..

This outlook means that, if possible, consistently with its highest good, no more than 145 millions construction cost should be dedicated to this enterprise by the Government of the United States, in addition to the present investment. There is not a business or commercial warrant for the canal at an appreciably larger price, returning for it but a 35-foot channel. There is, however, every warrant in commercial outlook and in military necessity for a canal costing an outlay, aside from interest, of the 145 millions of money allotted by Congress in the Spooner Act.

FINANCIAL COMPARISON OF FORMER ESTIMATES.

From the standpoint that the commercial uses of a canal warrant the expenditure on construction of not over $145,000,000, it is in order to compare the estimates of all projects.

For each of the other plans there have been made estimates purporting some of them to be detailed and others confessedly at hazard. In any comparison of costs these estimates will be used, but only because none better exist. Prefacing any utilization of the figures for purposes of comparison, it must be stated that they are not fair criteria because:

First: None are for a channel deeper than 35 feet or of adequate section. The author's Canal is 40 feet deep and of 8,000 square feet least section. Prices should relate to the same prism.

Second: The premises on which comparative estimates have been heretofore made were not correct.

In estimating and comparing the probable costs of the various projects, one and all have based their computations upon unit prices which they call identical for each proposed design. The same unit prices even were used in 1901 in comparing the total costs of Nicaragua and Panama.

Any reliable estimates must go far deeper. The ultimate cost of the Isthmian Canal depends primarily upon two main factors. The first is the project adopted. On this rests the amount, place, character and distribution of the excavations, the relative portions that may be done with land and floating plant, the location and design of the structures, the means and methods of execution, the sanitary conditions, and in general all the physical as distinct from the personal elements. The second main cost determinant is bound up with administration. It includes the personal aspects of the work prescribed, the correctness and efficiency of its execution, together with sanitary and police expenditures.

With the latter this discussion does not undertake to deal. That the most efficient organization for the active prosecution of work will be adopted is presupposed. Once a definite project and program have been selected, there can be small doubt that the contract system will be employed and the work of the government engineers will be chiefly to keep track of what is done. The task of holding high the level of real efficiency and of selecting the best plant and methods, will then devolve on men whose fortunes are at stake and whose executive experience and capacity have brought them to the commanding posts which they will hold.

Assuming the fullest adequacy of the personnel, government and contracting, the estimates of cost should then be on the basis of physical dispositions. Such estimates, however, depend upon a comprehensive knowledge of the material, the volume, and incident conditions of execution. To prepare them requires a scientific investigation of their relations to each plan, by competent men directing their observations over all the territory to be dealt with and applying a mature experience of unit costs. Actual working tests, if attempted, must be made under such conditions as will render them really typical. The Cost of the Culebra cannot be rightly ascertained by a short steam shovel trial in the most favorable season. The cost of deepening the channel through the swamps cannot be settled by the price of dredging its recent silt banks with a rehabilitated dredge.

UNIT FIGURES OF FORMER ESTIMATES.

A schedule of unit figures identical for each instance, and some announced as a recent "revelation," since proved untrue, from work extended over a month on the use of three or four new steam shovels, has been applied to the 60 feet, and 30 feet, and the Sea-level estimates. This the writer submits is in principle a radical and pernicious mistake.

In the latest official estimates the following statement occurs:

> "The above estimate is based "primarily upon the unit priced adopted by the former Isthmian Canal Commission, as contained in its official reports, modified, however, by the results of the actual experimental work conducted under the personal direction and observation of the Chief Engineer. The quantities and unit prices are considered sufficient."

The unit prices adopted and employed by the Isthmian Commission of 1901 were as follows:

"Removal of hard rock, per cubic yard	$1.15
" " soft rock, " " "	.80
" " earth, not handled by dredges, per cubic yard	.45
" " dredgable material, per cubic yard	.20
" " rock, under water, per cubic yard	4.75
Embankments and back filling, per cubic yard	.60
Rock in jetty construction, per cubic yard	2.50
Stone pitching, including necessary backing, per square yard	2.00
Clearing and grubbing, in swamp sections of Nicaragua, per acre.	200.00
Other clearing and grubbing, on both routes per acre	100.00
Concrete, in place, per cubic yard	8.00
Finished granite, per cubic yard	60.00
Brick in culvert lining, per cubic yard	15.00
All metal in locks, exclusive of machinery and culvert linings, per pound	.075
All metal in sluices, per pound	075
Cast iron in culvert lining, per pound	.04
Allowance for each lock chamber for operating machinery	50,000.00
Additional allowance for each group of locks for lower plant	100,000.00
Price of timber in locks, per M.B.M.	100.00
Sheet piling in spillways, per M.B.M.	75.00
Bearing piles in spillways, per linear foot	.50
Average price of pneumatic work for the Bohio Dam, below elevation—30, per cubic yard	29.50
Single-track railroad, complete, with switches, stations, and rolling stock, per mile of main line	75,000.00

It has been determined to add 20 per cent. to the estimates of the cost of construction to cover expenses that will be incurred for engineering, police, sanitation, and general contingencies. The prices are based on efficient organization and thorough equipment, with the understanding that while the work would be vigorously handled, it would not be so driven as to call for unnecessary duplication of machinery. The cost of the equipment and plant will be large, but it will be distributed over a very large work."

The following are the more important unit prices, including labor and transportation of materials used for the original estimate of the Comité Technique:

Dredging, 3 francs and exceptionally 3.5 francs per cubic metre (44 to 52 cents per cubic yard).

Excavation in earth 3.5 francs per cubic metre (52 cents per cubic yard).

Excavation in rocky material 5.5 francs per cubic metre (81 cents per cubic yard).
Excavation in the deep cut varies from 3.5 to 5.5 francs per cubic metre (52 cents to 81 cents per cubic yard) according to locality.
Masonry for the locks and spillways 50 francs per cubic metre ($7.38 per cubic yard).
Masonry for the Alhajuela dam 60 francs per cubic metre ($8.85 per cubic yard).

It has been demonstrated that no two projects will work out at the same unit costs at Panama, and that the variation will be very great. Local conditions created and methods of execution applicable to the different designs or Canal levels, have everything to do with varying the unit costs of construction. Hence, by the force of logic, the old comparative system of estimating cannot lead to anything but unfair guesses.

The estimated cost of the various structures has been on a par with this. For one instance in the 1905 report on the basis of which the Engineering Committee recommended a Sea-Level canal, the cost of this canal is given as $230,475,725. One of the main items is "Gamboa dam and Spillway, $10,000,000."

In the report itself little mention of the real conditions was made. Yet it is needless to say that upon the material to be encountered in making the tunnel depends not alone its cost, but the feasibility and safety of the whole enterprise—the very existence of the Canal built under that plan.

A field report on which this estimate was based and the recommendation launched describes as follows the material of which the tunnel site is composed.

"As located on the map, the length of the tunnel would be about twenty-three thousand (23,000) feet, all of which would be probably through rock varying from soft limestone to medium hard basalt." Nothing but this constitutes the data for an official and momentous decision for a crucial item of the latest "estimates."

There were no borings ordered or made, though a location 18,000 feet long was reported found.

FINANCIAL COMPARISONS.

But certain financial relations must be determined for a thorough understanding of the problem, so for tentative purposes the official figures are taken:

For the Sea Level	$230,475,725
30 foot Level	194,213,405
60 foot Level	178,013,405
85 foot Level	144,233,358

Working out the various items which go to make a business investment for these, the result is as given in the following tables:

CONSTRUCTION.

	Total cost (construction cost plus $53,000,000).	Interest during 10 year construction period.	Deficit for opening years of operation, 1915-16-17.	Total capital required.
85 ft.	$197,000,000	$24,700,000	$12,000,000	$233,700,000
60 ft.	231,013,000	28,101,300	15,385,700	274,500,000
30 ft.	247,213,000	29,721,300	16,965,700	293,900,000
S.-Level.	283,500,000	33,350,000	20,550,000	337,400,000

OPERATION.

	Interest 2% per annum on total capital.	Sinking fund and extraordinary contingencies at ¾%	Total yearly expenses including $2,000,000 for operation.	Income for 1918 from tonnage at $1.00 net ton.
85 ft.	$4,674,000	$1,752,750	$8,426,750	$7,606,555
60 ft.	5,490,000	2,058,750	9,548,750	7,606,555
30 ft.	5,878,000	2,204,250	10,082,250	7,606,555
S.-Level.	6,748,000	2,530,500	11,278,500	7,606,555

OPERATION.

	Deficit in 1918.	Years after opening: When operation expenses=income.	Income for 1927 from tonnage $1.00 net ton end 1st decade.	Difference between expenses and income for 1927.
85 ft.	$820,195	5.5	10,554,550	2,127,750 Surplus.
60 ft.	1,942,195	8.9	10,554,550	1,005,800 Surplus.
30 ft.	2,475,695	11.6	10,554,550	472,300 Surplus.
S.-Level.	3,671,945	Not in decade	10,554,550	723,950 Deficit.

From the above, the effect on the results of increasing the Construction Cost is apparent. For each case $50,000,000 is considered as having been already invested, while the remainder of the Total Construction is to be paid out at a uniform rate during the ten-year construction period.

It is of interest to institute a final comparison between the Authorized Canal costing $145,000,000 and the Sea-Level plan, which was recommended early in 1905 by the Engineering Committee of the Commission, in accordance with Government financial methods.

The principal recommendations were summed up in this resolution:

> "That this committee approve and recommend for adoption by the commission a plan for a sea-level canal, with a bottom width of 150 feet and a minimum depth of water of 35 feet and with twin tidal locks at Miraflores, whose usable dimensions shall be 1000 feet long and 100 feet wide, at a total estimated cost of $230,500,000.

> "Such estimate includes an allowance for administration, engineering, sanitation and contingencies, amounting to $38,450,000, but without allowance for interest during construction, expense of zone government and collateral costs, and water supply, sewers or paving of Panama or Colon, which last items are to be repaid by the inhabitants of those cities."

It is assumed that deficits would be paid; that the first surplus earnings would be applied to refunding the cumulated deficits; that the surplus earnings after the deficits are made good would be applied to a Reserve Working Fund of $10,000,000; that the surplus earnings after the above fund is complete would be applied in any manner prescribed by Congress, but always with the provision that any draft on the Working Reserve Fund due to contingencies or new construction shall be restored before the surplus is used for any other purpose. No contingencies or extra expenditures which would involve drafts on the reserve working fund will be considered.

As to bonded indebtedness, first of all, Congress has authorized the issue of $130,000,000 in bonds for the Panama Canal. The recommendations of the Committee for a sea-level canal estimate a construction expenditure of $230,500,000, which, as per schedule, will require the authorization of $85,500,000 bonds additional, or a total of $215,500,000. These sums represent the bonded indebtedness.

YEARLY FINANCES
OF
AUTHORIZED AND SEA-LEVEL CANALS.
GOVERNMENT FINANCING.

YEARS	AUTHORIZED CANAL $130,000,000 BOND ISSUE			FOR BOTH PROJECTS	SEA-LEVEL PROJECT $215,500,000 BOND ISSUE		
	Remarks.	Difference.	Expenses.	Income.	Expense.	Difference.	Remarks.
1915	Deficit	$3,600,000	$4,600,000	$1,000,000	$6,310,000	$5,310,000	Deficit
1916	Surplus	400,000	4,600,000	5,000,000	6,310,000	1,310,000	Deficit
1917	Surplus	2,679,000	4,600,000	7,279,000	6,310,000	969,000	Surplus
1918	Surplus	3,006.600	4,600,000	7,606,600	6,310,000	1,296,600	Surplus
1919	Surplus	3.334,200	4,600,000	7,934,200	6,310,000	1,624,200	Surplus
1920	Surplus	3.661,800	4,600,000	8,261,800	6,310,000	1,951,800	Surplus
1921	Surplus	3,989,400	4,600,000	8,589,400	6,310,000	2,279,400	Surplus
1922	Surplus	4.317,000	4,600,000	8,917,000	6,310,000	2,607,000	Surplus
1923	Surplus	4,644,600	4,600,000	9,244,600	6,310,000	2,934,600	Surplus
1924	Surplus	4,971,200	4,600,000	9,571,200	6,310,000	3,261,200	Surplus
1925	Surplus	5,298,800	4,600,000	9,898,800	6,310,000	3.588,800	Surplus
1926	Surplus	5,626,400	4,600,000	10,226,400	6,310,000	3,916,400	Surplus
1927	Surplus	5 954,000	4,600,000	10,554,000	6,310,000	4,244,000	Surplus

REMARKS	Authorized Canal.	Sea-Level Project
Total Deficit	$3,600,000	$6,520,000
Total Deficit Refunded in	1917–1918	1920–1921
$10,000,000 Reserve complete in	1920–1921	1923–1924
Available accumulated surplus end 1927	$34,283,000	$12,053,000

Since every project heretofore proposed fails to realize the size and completeness of the people's wish, as registered by Congress, there must be added to the "estimates" of the Commission of 1901, of the Comité Technique and of these later pronouncements the further millions of uncounted cost and interest and deficits which belong to them for creating a 40-foot canal.

COST OF PROJECTS A, B AND B′.

EXCAVATION.

Volumes.—There are certain very pertinent general facts as distinct from detailed estimates that will bear vitally upon and help determine the question of which Project is the best. One of these is the excavation volumes as related to the work left by the French.

From 20,000,000 to 22,000,000 cubic yards were dug by the old and new companies, in the sea-level stretch between the Atlantic Terminus and Bohio. Except in a few places where the channel has silted up, there now exists a cutting about 72 feet wide at the bottom and 200 to 250 feet at the top and 20 or more feet deep. Assuming that the older plans accept the new terminal location, which is certainly and indisputably one improvement that can be made without a change in their intrinsic form, there becomes available this dredged channel somewhat silted up, extending from Mindi to near Bohio, about 10 miles, at ocean level. Under any of the older plans contemplating the retention of this reach at sea-level, it is necessary in order to secure a forty foot channel of the cross section already determined: 1st. To improve the whole channel, deepening it some 20 feet and taking from one side a slice about 80 feet wide by 45 feet deep for the whole distance. 2nd. To rehandle the material in one of the old spoil banks, moving it further back.

In the projects of the author there will be little of this work necessary. A 27 to 33.5 foot level of the lake in Project A added to the 20 foot channel already existing will give the depth wanted without further dredging. At the Panama terminus similar conditions will rule, as the terminal lakes will cover 17¼ miles. Among other savings inherent in the two terminal lakes, Lake Chagres makes possible the Gatun Cut-off eliminating 76° 21′ of curvature and 1.2 sea miles of canal length, with comparatively little extra excavation.

A graphic idea may be secured of the relative excavation rank of the various projects by means of the comparative longitudinal profile, along the axis of the Canals. Each different scheme uses more or less of the French excavation and the volume either side of the centre line. With all but the Projects A, B, and B′, the old French spoil banks must be largely redug and redistributed, so that the actual slope quantities will work out differently with each design, in every instance favoring the plans of the author.

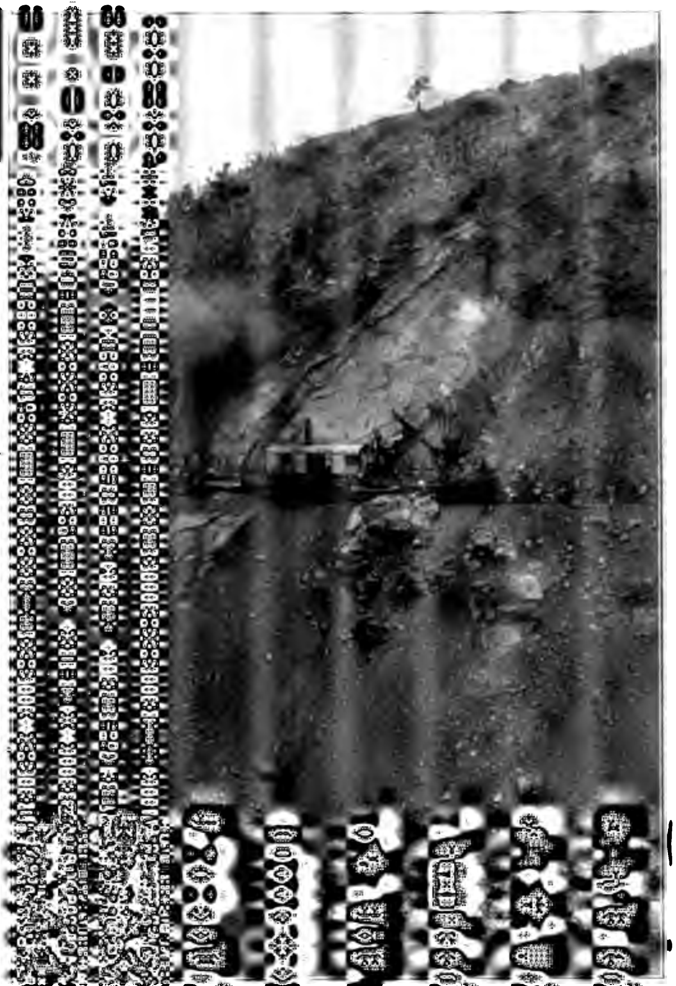
EXCAVATION COMPARISON.

PROJECT.	LENGTH OF EXCAVATION (SEA MILES).	AVERAGE DEPTH OF EXCAVATION.	AVERAGE SLOPES 2 ½ TO 1 SEA LEVEL 100.
B¹	27.2	41.6	26.5
Gatun Dam Project, 100 feet	29.8	38.3	26.0
French Project, 130 feet	51.0	29.8	30.9
Isth. Comm. 1901, 85 feet	42.0	38.9	37.1
B	42.0	40.0	38.5
Comité Technique	51.3	40.0	47.1
A	43.2	57.9	67.7
30 foot Project	51.3	54.2	72.9
Sea Level	51.3	66.9	100.0

This table does not embrace large and expensive river diversions, features of all plans but A, B and B′.

UNITS COST OF EXCAVATION.

Plant and Method. Besides the volume and classification of excavations there is an equally important cost determinant—the manner in which the work is to be accomplished. The excavation problem is a fivefold one, of labor, of plant, of method, of transportation and of spoiling. Each of these factors is of the greatest significance in determining canal costs because each helps fix the amount for which a cubic yard can be disposed of. It is an almost self-evident proposition that so far as regards labor efficiency in the tropics the scheme permitting the economical employment of the greatest amount of floating plant is, in this respect, the best and cheapest. If under one plan a certain work is done by a well equipped dredge, floating on an open fresh water lake, with a small crew and men of high grade; if under another there must be employed gangs of Jamaica negroes, or coolies, housed perhaps well, but living as such people always do, then there is bound to be a very great cheapening in the [illegible] ation under the first. Every improvement in sanitary [illegible] proportionately great diminution in the cost of work. [illegible] a unit lost from production; he is a greatly increased



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use to be made of floating plant and of such machinery as employs relatively few but high grade men.

A second great advantage beyond this personal efficiency is the better facilities such plant has to cope, all other things being equal, with the physical conditions here in the tropics. The removal from the section between Obispo and Miraflores of say some 14,000,000 cubic yards below the high tide plane is inherent in the sea-level plan. This excavation must necessarily be done "in the dry" by excavators or steam shovels and be taken away by trains. An item of allowance for dumping and lifting these and other tens of millions of tons from the vast saturated pit is surely in order. They must be lifted mechanically and at great outlay. But the steam shovel schedule of "unit costs" quite ignored such facts. The factors of lifting, pumping and transporting in a sea-level summit cutting will be manifestly higher than under any other project. Rain gives excavation "in the dry" in the wet season a serious handicap. Efficiency under such conditions is therefore much less than results achieved "in the dry" in the United States would lead one to infer. There is much dear pumping, sinking of tracks, disorganization and many accidents to put up unit prices. These are best eliminated when as much work as possible is done by dredges, whose natural element is water.

In the cut at ocean level from Mindi to Bohio, inherent in every former plan, some 30,000,000 cubic yards of earth are to be dredged and placed in adjacent spoil-banks. This quantity weighs over ten billion pounds. Each of these pounds has also to be lifted an average of 15 feet above water in order to be distributed. This, interpreted, gives 150 billion foot pounds of work. But it takes eight pounds of water to distribute one pound of material hydraulicly, hence, the lift calls for 1,350 billion foot pounds of work. If, instead, a lake is created nearly all of this vast extra work, entailing great outlay of money, time and life, is obviated, and dredges attacking the cuts between Bohio and Obispo will save a vast expenditure for power. The swamp excavation necessary for all the old projects on the Atlantic end is in earth almost entirely, although increasingly dense below —18. But on the Pacific end, to bring the channel down to 50 feet below sea-level, there is much rock to be excavated. Submerged rock removal costs some 30 times what ordinary dredging does. The saving effected by a Lake Panama at +27 will be in consequence of diminishing this rock work, very great.

For the mixed material occurring in the Summit Section, similar methods will probably be applied under all plans. The strata will require blasting though the material is not specially difficult for ordinary dry excavation. There is required for the Culebra, proper terracing and draining, efficient laborers and foremen and good excavators, (not by any means necessarily steam shovels,) and a thoroughly well thought out system and steam or electric train distribution. To sum up, the author's plans make available for attacking all sections, plant which works under the most favorable conditions possible.

Distribution of Spoil.

A principal cost factor at Panama, aside from the mere brute volume of the central divide is that of distribution of material. A good relief map will show that the available valleys are far too small and too imminent to safely hold the summit excavations. To distribute by train over the marshes behind Panama, is to pay a heavy toll of life and not get rid of half the spoil, as well as to forego all the advantages of Lake Panama in transit time, inner harbor and sanitation. By process of elimination the only available spoil area becomes the Pacific Ocean. But to avoid the effect of littoral drift, spoil should be carried 10 miles to sea or be put where there is no drift. The recent claim of "50 cents a cubic yard for the Culebra based on actual costs," is entirely misleading. No calculations were made of the increased cost at greater depth and none of the increasingly longer haul. Such factors of cost were not even considered, apparently. Transportation by trains involves the corollaries of grading, loading, unloading and spreading and temporary tracks. A perfect train service direct to the Panama Reclamation from Culebra is essential, but in addition, by one terminal lake, the channel becomes available at once to the immediate vicinity of the works, without some years of costly and unhealthy excavation. Thus the summit may be attacked from the ends and water transportation of spoil employed, both expediting the work and lowering the unit costs. The plans for utilizing Culebra spoil were developed in the Chapter upon New Panama. Breakwaters will enclose the whole harbor with giant rocky arms. These can be made by dumping from barges. To make a new town site, of the Culebra rock, sanitary and clean, over the tidal shallows of Panama, one rail haul will suffice, so that two transportation and dumping means and locations are available. The value of this property at current Panama prices would be several million dollars.

If these dispositions are to remain available as a solution, there must be no spoil distribution in localities that would preclude them.

If, however, during the time which will be consumed in deciding the plan for the Canal the spoil of Culebra is not taken outside the watershed of the Canal, or at least properly confined within naturally enclosed valleys or behind substantial débris dams, it can only be put to sea or in the lower valley of the Rio Grande where it will preclude the creation of Lake Panama.

Further, a Culebra track system has been planned in connection with the Sea-Level scheme to transport material in part to and above the Gamboa dam site and to waste spoil there in the watershed of the Chagres. This course would limit the area and jeopardize the creation of the Gamboa Catchment Basin—an essential and vital feature of the new Projects. Such disposition would be less harmful to the 30 and 60 or 85 foot Central Lake proposals, although objectionable for them also. It is to be remarked, that expenditures at Colon, such as water supply, sewage, filling, docks, coal bunkers, fuel, oil tanks, together with Christobal harbor excavation, etc., etc., should be of only temporary, through effective, character, because the best situation for permanent works is at the Balboa site.

The transportation of supplies and machinery to the central divide region, forms an item in the original cost of the plant. The project that permits plant additions and renewals and supplies to be carried to the verge of the central cutting without transhipment into railroad cars, will be more advantageous than one which does not. This superiority is possessed by the author's plans as by no other. Every one of the causes mentioned will act cumulatively to reduce unit prices of excavation below those that could be possibly reached otherwise.

STRUCTURE COSTS.

The various structures that go to form part of any canal are another determining item. An analysis of comparative conditions is pertinent and valuable.

Dams. For solid high dams in all other projects, there are substituted dams of much lower height, with vastly less cubical contents, meaning less cost and less time and risk.

Tunnels and Diversions. In place of these the river has been so regulated as to flow down the canal to the two oceans. Their whole potential expense, construction, operation and maintainance is eliminated.

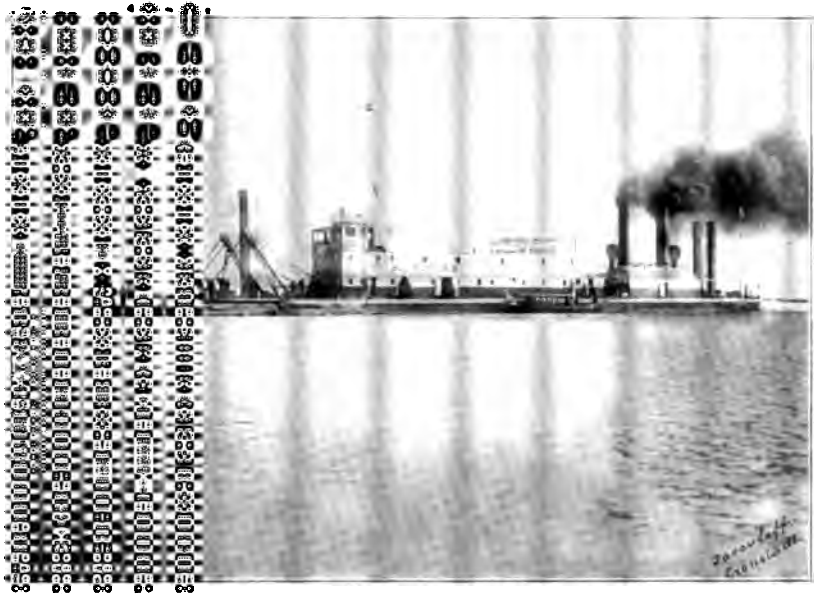
Locks. In each case for a given summit level, the author's plan may have two less interior locks affecting navigation than any other.

Barrages and Dykes. The one integral expense of the author's plan not matched by a higher one in the others is in these two items. The dykes are simply double rock fill, earth center dams of the Morison or of the best Holland type. The two terminal barrages total about 1,000 feet in length and are not over 43 feet high. So that these two items will not nearly counterbalance the others, and it may be safely stated that in structures too, a great saving is inherent in the new system.

MISCELLANEOUS DISPOSITIONS.

The utilization of oil, rather than coal for fuel and the installation of a pipe line to supply it, will effect a further great saving.

[illegible] the lakes first and locate the double tracked section [illegible] road between temporary terminals at their heads, avoids [illegible] ng double tracks over the whole extent of a road where [illegible] unnecessary in eight years.



[illegible] IA, NO. 8. BUILT FOR THE RUSSIAN GOVERNMENT.

[illegible] it is held as uncontrovertible that by the system here [illegible] canal can be constructed far more cheaply than under [illegible] tem that has been suggested, both as to absolute and [illegible]

[illegible]

[illegible]

It is under the assumption of a contract system with the greater economies and efficiency which it insures, and embodying his own experience in encountering hydraulics problems at home and abroad into his purposed means and methods, that the writer makes for himself his schedule of unit prices and arrives at the table of costs. In his deductions, conclusions and figures he has at stake not simply the deliverance of an engineering opinion but the pronouncement of an exact and final price behind which must be entrenched the capital guaranteeing a contract for the canal construction which his project proposes.

He submits that his Plans can be best executed by an organization having an adequate capital which will enable the whole work, engineering and executive, to be responsibly undertaken under proper safeguards, for the following definite sums per statute mile as and when completed, the Canal reckoned as forty miles from Sea to Sea, Government administration, sanitation and Policing costs not included.

Project A	$3,375,000	per mile
Project B	3,125,000	"
Project B′	2,787,500	"

ESTIMATES OF COST.

The following table embodies the official summary of estimates of the latest schemes for a 35-foot channel; the necessary 40-foot Canal will require an additional sum in each instance, and approximately 20 per cent. more including engineering may fairly be reckoned for realizing the larger waterway. The table likewise sets forth the proper costs for the execution of proposals A, B and B′:

OLD PROJECTS.

OFFICIAL ESTIMATES 35′ CANAL PROJECT WITH ESTIMATED ADDITION FOR 40′ CHANNEL.

BOTTOM WIDTH 150′.

ITEMS.	SEA LEVEL	30 FT. LEVEL	60 FT. LEVEL	85 FT. LEVEL
Breakwater, Colon.............	$5,000,000	$5,000,000	$5,000,000	....
Colon Inner Harbor............	8,373,000	8,373,000	8,373,000	8,057,707
Direct Entrance...............	1,500,000	1,500,000	1,500,000	....
Harbor to Bohio, with Levees....	11,099,839	11,099,839	11,099,839	11,099,839
Bohio Locks and Spillway........	....	7,000,000	9,000,000	11,567,275
Bohio Dam and Spillway.........	....	....	5,000,000	6,369,640
Pedro Miguel Lock.............	....	....	6,000,000	9,081,321
Excavation, Bohio to Miraflores...	125,000,000	86,000,000	59,500,000	....
Retaining Walls Culebra Cut......	10,394,794	10,394,794	10,394,794	44,414,469
Mira Flores Lock...............	4,000,000	5,781,401	5,781,401	5,781,401
Pacific Level..................	12,427,971	12,427,971	12,427,971	12,427,971
Chagres and Gatun Diversions....	3,000,000	3,000,000	3,000,000	2,029,982
Panama Railroad Diversion......	1,267,500	1,267,500	1,267,500	1,267,500
Gamboa Dam and Spillway......	10,000,000	10,000,000	10,000,000	....
Lake Bohio....................	....	....	....	2,952,154
Obispo Gates..................	....	....	....	225,434
Pedro Miguel Level.............	....	....	....	1,192,286
Gigante Spillway...............	....	....	....	1,209,419
Pena Blanca Outlet............	....	....	....	2,448,076
Total..................	192,063,104	161,844,505	148,344,505	120,194,465
Add 20% for Making 40 Feet	36,412,621	32,368,901	29,668,901	24,038,893
Channel and Engineering....	$230,475,725	194,213,406	178,013,406	144,233,358
Add for Administration, Sanitation and Contingencies...........	20,000,000	15,000,000	13,500,000	12,500,000
Grand Total for 40 Feet Canal	$250,475,725	209,213,406	191,513,406	156,733,358

NEW PROJECTS.

ESTIMATE FOR PROJECTS A, B AND B′ FOR 40′ CHANNEL.

BOTTOM WIDTH 150′ CONSTANT.

	B	A	B′
Lock, Barrage Dyke, Breakwater Balboa Harbor	10,000,000	10,000,000	10,000,000
Harbor to Gatun	....	....	....
Gatun Lock Dam & Barrage Pedro Miguel	7,500,000	....	7,500,000
Lock and By Pass	7,000,000	....	10,250,000
Gatun to Pedro Mig.	69,750,000	93,000,000	45,000,000
Panama Harbor & Sosa Lock	10,000,000	10,000,000	10,000,000
Pedro Mig. to Sosa Naos Island	3,000,000	3,000,000	3,000,000
Railway Diversion	1,250,000	1,000,000	1,250,000
Alhajuela, Gamboa, and Cano- Dams	8,000,000	8,000,000	8,000,000
	....	....	....
Miscellaneous	8,500,000	10,000,000	9,500,000
Bohio Lock &c.	....	....	7,000,000
....	....	....	....
....	....	....	....
Construction..........	125,000,000	135,000,000	111,500,000
Administration, Sanitation, etc...........	9,000,000	10,000,000	8,500,000
Grand Total..........	134,000,000	145,000,000	120,000,000

CHAPTER XII.

CONCLUSION.

Having outlined the essential elements of the System and the Projects for the Panama Canal, the time has come to weigh all in the final balance, not with a prejudiced but with an open-eyed justice. There are two designs which can profitably be compared with the Lindon Bates' plan—the Sea Level, and the 61.5 foot scheme as evolved by the Comité Technique. Each stands for a type and represents the best embodiment of the principles ruling their structure. The decisive question becomes here at the close: 1st. Wherein is the Sea-Level Canal as detailed by its latest official advocates inferior? The answer will be summed up in the following category of defects and objections:

SEA LEVEL SYSTEM.

Dimensions. Channel to a depth of only 35 feet with dimensions which barely allow passage of latest war vessels and which will not pass the newest liners.

Channel. Most bank length to be eroded.

Highest spoil banks.

Most cost to widen or deepen later when canal is in use.

Diversions certain to be silt clogged.

Dam and Spillway System. The Gamboa Dam is a gigantic 200-foot Masonry core-earth structure very difficult to maintain during construction of dam and tunnel.

Great head of water up to 180 feet permanently impounded above canal.

Rock foundations not found suitable for core 200 feet high.

Disaster in case of cave-in of tunnel.

Problematic in construction and operation.

Most Lower Chagres Diversion Work.

Excavation. Highest unit cost of excavation.

Most plant.

Most excavation.

Least utilization of French excavations.

Most submerged rock excavation at Panama end.

Greatest consumption of fuel in construction.

Most pumping during construction.

Greatest difficulties in distributing spoil.

Sanitation. Least sanitary.

Swamps and disease foci all retained.

Most common labor and incident sickness and loss of life.

Navigation. A constricted lakeless channel for the whole distance.

Greatest risk to vessels in transit.

"Northers" at Atlantic entrance, able to occasion detrimental currents.

Poorest harbor facilities.

Fewest turning basins.

Fewest passing stations.

Channel section areas not compensated to equalize currents.

Greatest curvature affecting navigation.

Longest transit time.

Least average speed.

Pacific section tide harried for 6 miles.

Financial. Greatest first cost.

Greatest expense for interest and maintenance.

Least net earnings.

Highest deficits.

Legal. Requires additional legislation to overrule fundamental provisions in Canal Law.

New appropriation needed to cover excessive cost.

Labor. Most difficult to secure and hold labor.

Not one of these impeachments can be successfully met. If it be answered that dimensions will be increased, then the cost estimated on the old dimensions must be increased to match. The figure is now $85,000,000 over the amount allowed and considered ample by Congress. Presumably the latest Sea-Level Canal plan represents the best that can be evolved for it. On the facts incorporated into this, the indictments stand.

The 61.5-foot plan, as adopted by the Comité Technique is taken as typical of the central lake schemes, since no one will now seriously entertain a dam to sustain an 90′ head or higher in the Gap of Bohio, or Gatun, and for the Lower Level a two lake storage scheme is necessary. Wherein is the Comité Technique project inferior? Its defects and objections are summarized likewise as follows:

CENTRAL LAKE SYSTEM.

Dimensions. Too small as planned.

Too costly if changed.

Channel. Diversions certain to be silt clogged, and poorer facilities to deal with silt at upper end of lake.

Utilization of only half of the canal cutting purchased by the Government in the section from Limon to Bohio.

Chagres and Rio Grande Swamps retained for 17¼ miles.

Dam and Spillway System. Bohio Dam twice a necessary head,—old design impracticable,—new design of Morison type of vast size.

Giganté. Weir regulation faulty.

Great and sudden variations of Lake Level.

Diversions. East diversions to Manzanillo Bay carrying floods of Gatuncillo Watershed parallel to Canal.

Below Bohio, expensive, West diversion of Chagres, including carriage of great volume from Giganté Spillway, parallel to Canal.

Diversions difficult to clear, excavate and maintain because exposed to resilting.

Lockage. Lockage supply capacity comparatively limited.

Excavation. Excavation of very tough clay below 18 feet in Atlantic Coast section, unhealthy and expensive, amid Chagres swamps.

More difficult to secure and hold labor.

More plant, more labor, more time for construction.

More submerged rock excavation Pacific section.

Navigation. Pacific Terminal waters, tide-harried for 6 miles.

No available and contiguous fresh and salt water harbors at either end.

Undue and detrimental currents at Obispo end of Lake Bohio.

No fresh water Naval stations convenient to termini.

Fifty per cent. longer transit time.

More Lock Leakage.

Sanitation. Little inherent in plan. Main marshes unsubmerged. Disease foci retained.

Financial. Greater excavation, unit and total costs.

Greater yearly interest, operation and maintenance costs.

Legal. Without nullifying or altering fundamental statute provisions in the Spooner Act, the canal cannot be built.

New appropriations needed.

All of the above indictments and more stand against the 85′ Project of the Commission of 1901. These disadvantages, also, are unanswerable, nor have the plans any saving features to redeem them.

COMPARISON OF PROJECT A, B AND B′

Since the author's preferred designs furnish several applications of the principles advanced, is becomes concludingly in order to decide of these, which will furnish the best canal. The concrete advantages of A over the other two are, detailed:

Project A. It is the simpler.

Its transit time is slightly shorter.

Has fewer locks.

Less diversions of Panama Railway.

No questions of cost and maintenance of the extra Locks, Dams, Spillways and Pedro Miguel By-pass.

Least care during operation.

Superiorities of Project "B" over "A" are:

Project B. Less expenditure.

Quicker to construct.

More sanitary because of third lake.

Less excavation in the central section.

Submergence of the low valley between Bohio and Obispo and all the various constructive and sanitary advantages attending the condition thus created.

Shortening of construction time by a year or more.

Lake Gatun or Bohio takes better care of the local streams emptying into it than Project "A" can provide.

The lake takes the place of the expanded channel of "A" from Obispo-Triangle northward.

Less Bank length to be maintained as Canal banks are submerged.

Lower unit cost of excavation.

Less curvature effecting navigation.

More turning basins and natural passing places.

Less pumping during construction.

Project B′, imposing a middle dam at Gatun, has certain disadvantages and certain advantages which are likewise scheduled:

Less natural lockage supply.

Longer transit than A or B.

Risk, cost and maintenance of two extra locks and Gatun dam and Barrage.

More expensive location of Panama R.R.

The corresponding advantages are:

Cheapest and quickest to construct.

Least excavation.

Least amount of submerged channel through lakes.

The fact that Project B′ involves several extra structures and a greater complication in operation, is of sufficient moment to make it inferior to Project B.

While the author's high level alternative B′ has the superiority of less excavation than any other, and corollaries of more rapid execution and reduced cost, the recognition that its tonnage capacity though inherently much greater than any of the older plans is, as to the long future limited, has satisfied him that it is not the best canal.

Lockage being practically the same therefore for the two projects, A and B and over 50,000,000 tons, the preponderance of advantage, unless it be decided that the level of A can be advisedly raised, lies with Project B with a Gatun Dam.

Therefore, that application of the author's system which is incorporated into Project B is the one which were best adopted for the American Canal. Under its arrangement the total cost need not exceed the $135,000,000 left from the Congressional appropriation. In three years from March 4, 1906, a "Celtic" and a "Manchuria" can greet each other from the ends of the Culebra Section, only 9 miles apart. In less than four years more the completed Isthmian Waterway can be inaugurated.

TABULATED COMPARISON OF PANAMA PROJECTS.

CRITERIA	COMITÉ TECHNIQUE	COMMISSION OF 1901	NEW SEA LEVEL	30 FOOT PLAN	LINDON BATES' SYSTEM		
SUMMIT					PROJECT A	PROJECT B	PROJECT B'
Summit level in Feet above Sea.	61.5'	85'	.0'	30'	26.5'	62.5' 33.5' 26 5'	96.5' 62.5' 33.5' 26.5'
Number of Locks.............	5	5	1 Sea Lock	2	2	4	6
Ruling Dimensions...........	35' x 150'	35' x 150'	35' x 150'	35' x 150'	40'to 45' x 150'	40' to 45' x 150'	40' to 45' x 150'
Lake Navigation.............	11¾ miles.	11¾ miles.	None	5 miles.	17¼ miles.	26 miles.	26 miles.
Chagres Control.............	61.5 head dam Parallel diversions	85' head dam Parallel diversions	180' head dam Tunnel and diversions	180' head dam Tunnel and diversions	Empty basin Divided Channel	Empty basin Divided Channel 35' net head dams	Empty basin Divided Channel Two 35' net head dams
Terminal Harbors............	Colon and Panama Roadsteads	Colon and Panama Roadsteads	Colon and Panama Roadsteads	Colon and Panama Roadsteads	Balboa and New Panama Fresh and Salt	Balboa and New Panama Fresh and Salt	Balboa and New Panama Fresh and Salt
Time of Completion..........	1915–18	1915–16	1916–18	1916–18	1914	1913	1912
Construction cost (official)....	$178,013,406	$145,000,000	$230,500,000	$194,213,406	$134,000,000	$145,000,000	$1[illegible]0,000,000
	Small prism	Small prism	Small Prism	Small Prism	Full prism	Full prism	Full prism

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Abbreviations: U. S., United States, Commission of 1901; C. T., Comitè Technique; L. B., Lindon Bates; S. L., Lates Official Sea Level Proposal,

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THE PANAMA CANAL

SYSTEM AND PROJECTS

OF

LINDON W. BATES

PLATES

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NOTE.

The page numbers following each descriptive paragraph refer to related matter in the text.

RELIEF MAP, PROJECT A.

The map here given is a photo-relief, which shows:

The four dominant ridges that make the three Isthmian valleys. These determine the four fundamental canal plans. 1. Sea-level cut through all four ridges. 2. Central lake with sea-level ends. 3. Terminal lakes and cutting through the central ridges. 4. Lakes in the three valleys. Page 10.

The watersheds, Upper Chagres above Gamboa, Central Chagres, between Gamboa and Bohio; Lower Chagres, Bohio to Chagres outlets; Rio Grande on Pacific Side. It shows also that an Atlantic Tunnel Spillway from the Upper Chagres must return the flood waters to the vicinity of the canal near Gatun. Page 19, 81.

The short gaps in the coast ridges, which are closed by dykes and barrages to make Lakes Chagres and Panama. Pages 14, 22, 23, 88, 158, 162, 168.

The two terminal lakes, at about the 27-foot level, of Project A, entered by end locks and made by low head dykes and sluice barrages. Pages 92, 109, 136.

All terminal swamps are submerged, thus drowning out extensive fever areas. Pages 123, 131.

The new general alignment of the Canal, Mindi and Panama entrances and the extent of lake navigation. Pages 50, 102, 135, 141.

The normally empty basins above the Gamboa, Alhajuela and Cano dams to receive Chagres floods. Page 72.

The Ruling Isthmian Points:

Culebra, main divide. Alhajuela, Upper Chagres Constriction. Gamboa, Limit of Upper Watershed. Bohio, Limit of Central Watershed. Gatun, Gap in Spur ridge. Mindi-Chagres, Chagres debouchments. Pedro Miguel, Pacific Tidewater Limit. Ancon-Sosa Saddle, Direct Panama sailing line. Page 19.

PROJECT FOR PANAMA CANAL.

Relief Map, Project A, Plate I.

RELIEF MAP, PROJECT B.

The combination end and central lake project. Lake Chagres and Panama at the termini and Lake Bohio in Medial Valley. Lake levels are Chagres 33.5′, Bohio 61.5′, Panama 26.5′. Pages 11, 14, 112, 136, 162, 168.

The four locks, two at canal termini, one at Bohio, one at Pedro Miguel. Pages 113, 162.

The normally empty catchment basins above the Gamboa Dam, to receive Chagres floods. Page 71.

The Bohio or the Gigante Spillway emptying into Lake Chagres far from canal line. Page 112.

The submergence of all swamps in or near Canal Zone. Pages 123, 131, 162.

PROJECT B′

The same relief map illustrates the project of least excavation B′, of which lake levels are Chagres 33.5′, Gatun 62.5′, Bohio 96.5′, Panama 26.5′ above mean sea-level. Pages 114, 162, 168.

The six twin locks, two at the termini, one at Gatun, one at Bohio, two at Pedro Miguel. Page 115.

PROJECT FOR PANAMA CANAL.

Relief Map, Project B, Plate II.

PROJECT FOR PANAMA CANAL.

Relief Map, Project B, Plate II.

PLATE III.

COMITÉ TECHNIQUE, MAP OF CANAL.

The Central Lake Canal at 61.5′ proposed by the Comité Technique. Pages 12, 83, 165, 169.

The old alignment starting with a reverse curve and ending at La Boca roadstead. Pages 12, 97, 100, 133, 141.

The swamps at Colon and along the greater part of the canal line. Page 123.

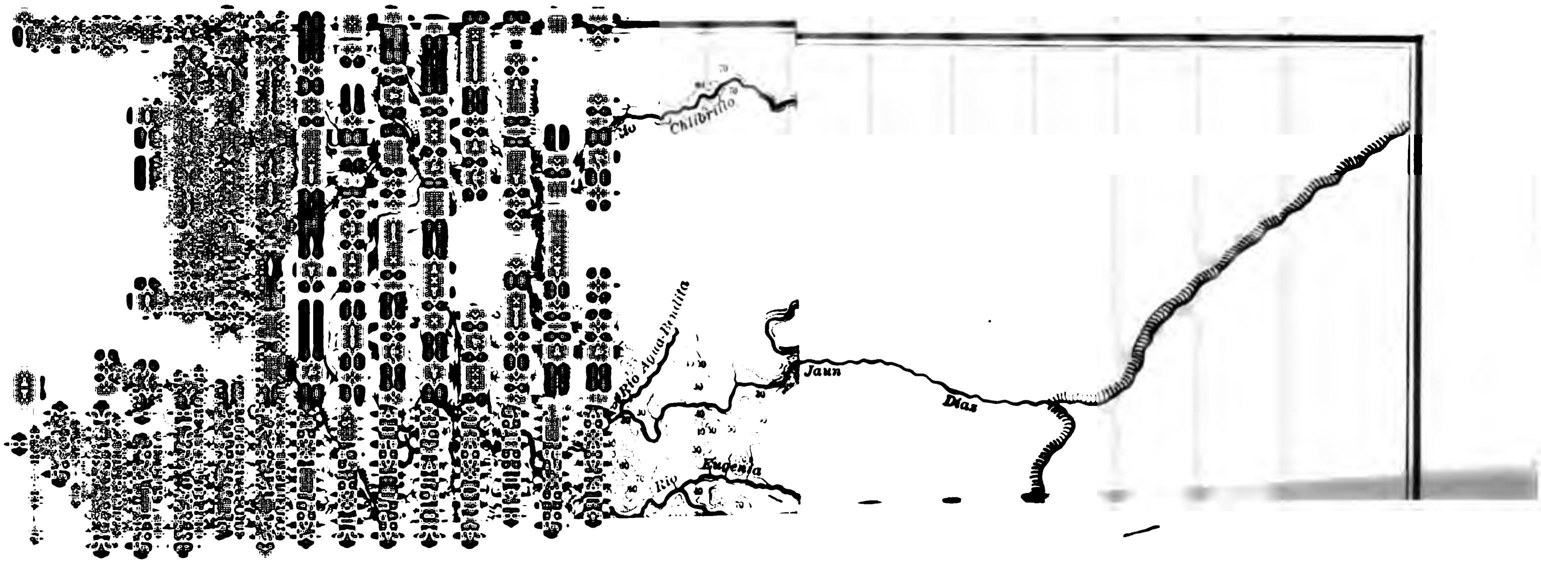
The numerous crossings of the Chagres River, necessitating parallel diversions on each side of the canal to take the river. Page 15, 83.

The numerous lower Chagres tributaries which will deposit silt in the diversions. Page 83.

The inadequate provisions at Colon and Panama for commercial and strategic harbors. Pages 16, 44.

PROJECT FOR PANAMA CANAL.

Comité Technique Map of Canal, Plate III.



PROJECT FOR PANAMA CANAL.

Comitê Technique Map of Canal, Plate III.

PLATE IV.

COMPARATIVE EXCAVATION PROFILES.

The approximate levels of the different plans and the positions and number of locks. Pages 12, 161, 169.

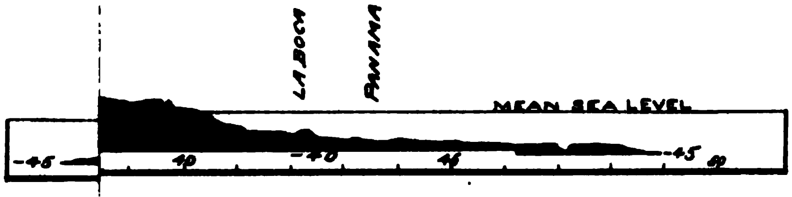
The longitudinal profiles of the different canal plans along their central axis, to give an approximate idea of excavation volumes. As shown by the analysis in the text, actual rank in execution works out more favorably for A, B and B′. This table does not include river diversions necessary for all the old projects. Page 155.

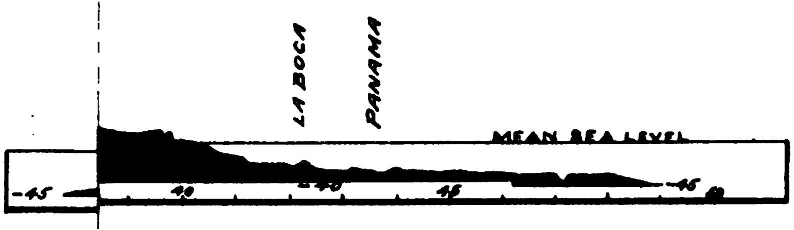
EXCAVATION COMPARISON

PROJECT	LENGTH OF EXCAVATION (SEA MILES)	AVERAGE DEPTH OF EXCAVATION	AVERAGE SLOPES 2½ TO 1. SEA LEVEL 100.
B′	27.2	41.6	26.5
Gatun Dam Project 100 ft.	29.8	38.3	26.0
French Project 130 ft.	51.0	29.8	30.9
Isth. Comm. 1901 85 ft.	42.0	38.9	37.1
B	42.0	40.0	38.5
Comité Technique	51.3	40.0	47.1
A	43.2	57.9	67.7
30 ft. Project	51.3	54.2	72.9
Sea level	51.3	66.9	100.0

PROJECT FOR PANAMA CANAL.

Comparative Excavation Profiles, Plate IV.





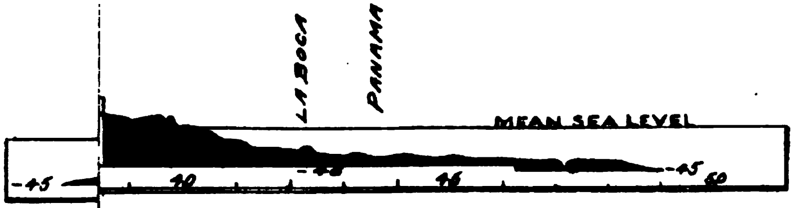


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PLATE V.

GAMBOA SLUICE DAM AND OBISPO BASIN.

The low head and short length of the dam proposed compared with the great curving Sea-level dam. Pages 72, 80, 162, 169.

The silt trap made by having sluices so arranged as to keep a pool above the dam, thus localizing sediment deposits. Pages 74, 85.

The separation of the Chagres Currents, sending half to either ocean through the Obispo Dividing Triangle. Page 75.

The adequacy of Obispo Triangle to prevent broadside currents from Gamboa discharge. Page 75.

PROJECT FOR PANAMA CANAL.

Gamboa Sluice Dam and Obispo Basin. Plate V.

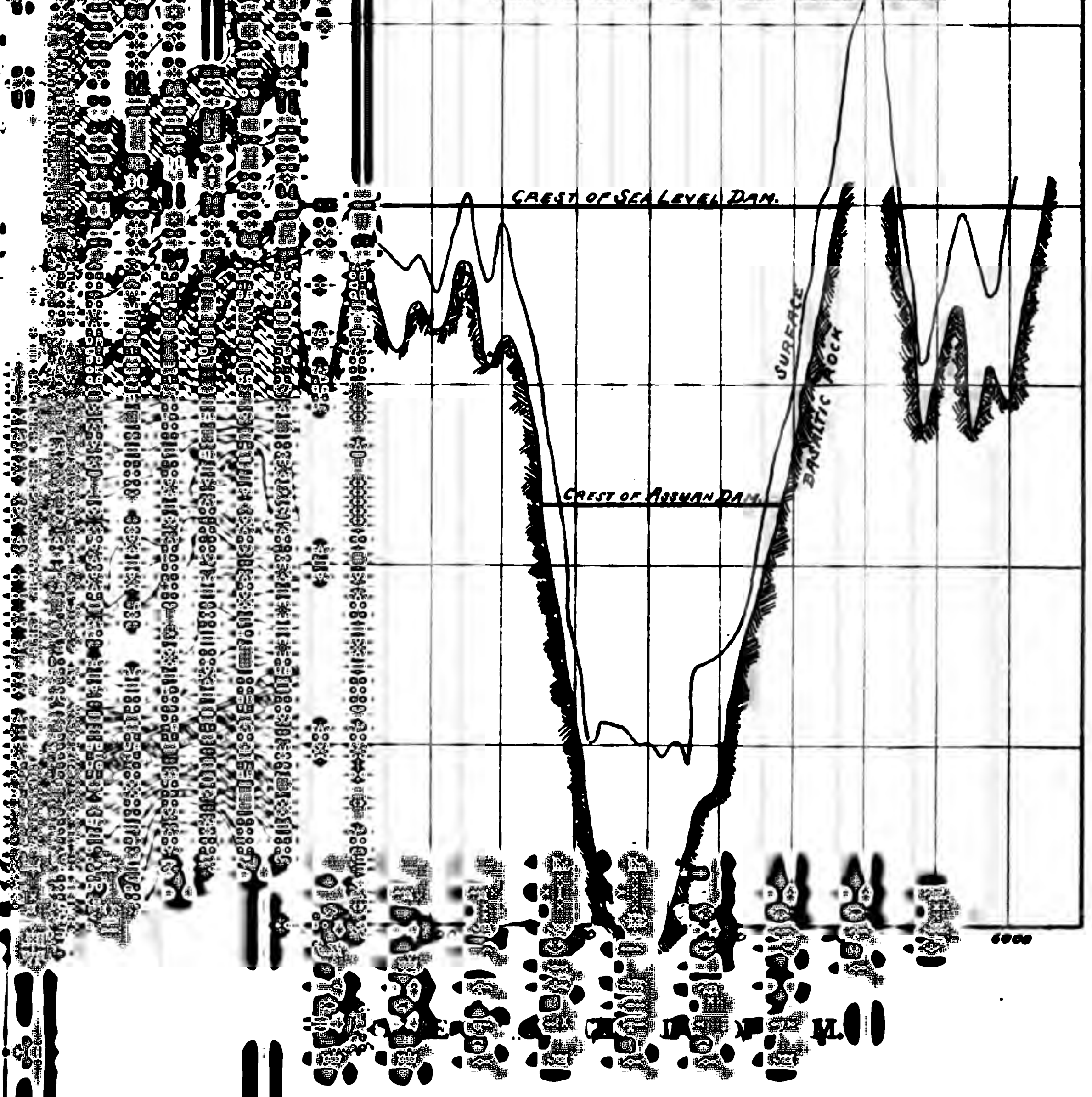

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PLATE VI.

HARBOR OF BALBOA.

Lake Chagres extending for 13.1 statue miles for Project A. Pages 16, 88.

The conformation of hills making feasible the barring of the old Chagres outlet by a short dyke and the Mindi outlet by a dyke and a short sluice barrage founded on rock. Pages 22, 91.

Cross section to show construction of Chagres dyke for 20′ to 40 ft. head, according to standard methods. Pages 68, 88.

The locations at which various local Chagres tributaries enter the lake, and will deposit silt far from the canal line. Page 88.

The new City of Balboa on an elevated and sanitary site, to supersede Colon on Manzanillo swamp. Page 96.

The new Atlantic entrance by the deepest and best course. Pages 96, 135

The salt water harbor atrium to the canal, the entering lock and the inner fresh water harbor and the naval station behind Jaramillo Hill. Page 97.

PROJECT FOR PANAMA CANAL.
Harbor of Balboa, Plate VI.

HARBOR OF GREATER PANAMA.

The extent of Lake Panama, formed by low head dykes and barrages, drowning all swamps in the vicinity of the City and Canal. Pages 14, 88, 123, 131.

The sections of Dykes and Barrages founded on rock, all on standard models. Page 68.

The outer salt water harbor made by two encircling breakwaters of Culebra rock whose heads are the Panama Islands. Pages 102, 162.

The Inner fresh water harbor and naval station behind Ancon Hill on Lake Panama, free from the 20 ft. Pacific tides. Pages 47, 102.

The new townsite made available by depositing Culebra spoil over the Panama flats to a height of 6 to 10 feet above high tide, thus making a sanitary site for the greater city. Page 105.

The existing wharf front of Panama and La Boca not disturbed nor vested rights injured by this new townsite, but both better protected by the breakwaters. Page 106.

The discharge from Sosa Barrage, directed along the new wharf front, preventing any damage from the teredo and barnacles. Page 101.

The sea bed contour of 7½ fathoms pointing directly toward the 1000 ft. entry between Naos and Perico Islands, which gives a straight sailing line to Miraflores through the lock. Hence the reduction of curvature and length of approach beyond all other plans. Pages 10, 136.

Alternative locations are shown for the entering channel but the straight course is best. Page 50.

PROJECT FOR PANAMA CANAL.

Harbor of New Panama, Plate VII.

PANAMA RAILROAD.

The diversions necessarily made on the railroad for the various Canal Plans are shown. As scaled, the distance in statute miles is approximately as follows:

	OLD LOCATION.		NEW LOCATION.		
PROJECT	MILES RETAINED	MILES ABANDONED	MILES NEW	MILES TOTAL	REMARKS
Sea Level....	30.5	16.6	17.7	48.2	
U. S. 30.....	30.5	16.6	17.7	48.2	45 on Bohio hill side
Comité Technique.	19.7	27.4	28.5	48.2	75 on Bohio hill side
U. S. 85.....	19.7	27.4	28.5	48.2	100 on Bohio hill side
Gatun 100...	13.2	33.9	57.3	70.5	Gatun Dam entails large extra expense to Ry. or resort to ferry.
130.........	19.7	27.4	28.5	48.2	
Bates A.....	30.5	16.6	17.7	48.2	Raise Present Grade for 13.5 miles
Bates B	19.7	27.4	28.5	48.2	Raise Present Grade for 13.5 miles
Bates B′.....	13.2	33.9	49.7	62.9	Resort to ferry or large expense for new location around Gatuncillo Swamp. Raise 9 miles.

LENGTH OF PRESENT LINE COLON TO PANAMA 47.1 MILES.

The profile shows the grade-raising that will be required for Project A. Page 92.

The Sea Level tunnel diversion locations are likewise shown and illustrate: 1. The length of a Pacific Tunnel. 2. The fact that the tunnel water from an Atlantic tunnel diversion runs to a channel with no slope from Gatun, 7½ miles to the mouth at Manzanillo Bay. Pages 19, 80, 153.

PROJECT FOR PANAMA CANAL.

Panama Railroad, Plate VIII.

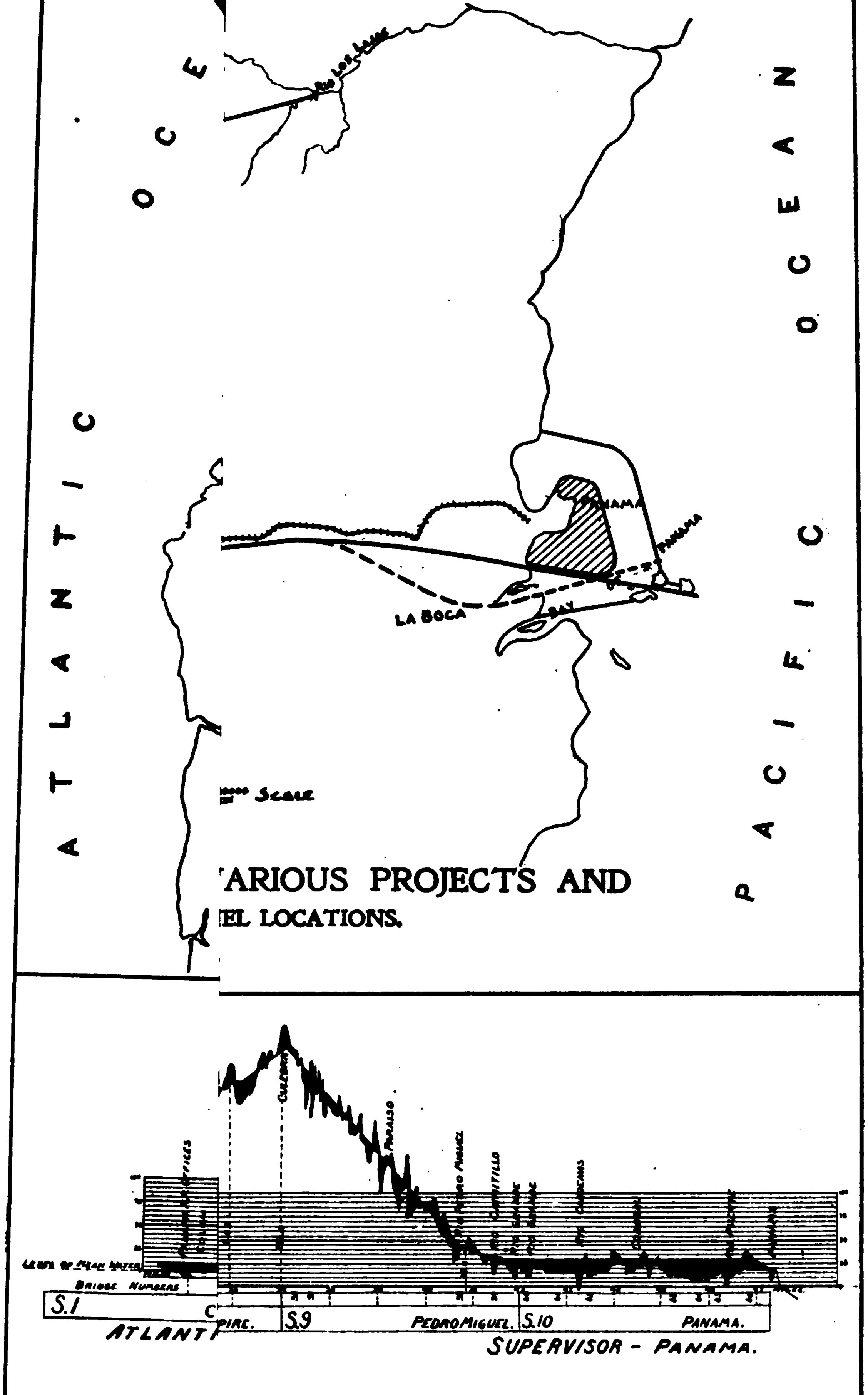

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PLATE IX.

RÉGIME OF THE CHAGRES RIVER.

In this plate are embodied the essential Isthmian data relating to flood freshet, mean and minimum discharges. Pages 24, 28, 42.

In the figure at the top of the plate, the lower line indicates for 18 months from 1900 the French results by the system of gaging and calculations they employed; the upper line shows the result obtained by the U. S. Hydrographer of the Commission of 1901. It is fair to state that while the tendency of the American observer may be to err a little on the side of largeness the discrepancies are so marked as shown by the consistent differences between the curves, that all they mean must not be ignored. Page 29.

The Cycle shows graphically all the French results concerning the daily régime from 1893 to 1900 at Alhajuela, Gamboa and Bohio. The full black line on the 44000 c. f. s. mark of the Gamboa circle discloses the important truth that during that decade there was no flood which would have necessitated the impounding of a cubic foot of excess water behind either the Alhajuela or Gamboa Dams, because only one flood reached as much as 37,500 c. f. s. (Dec., 1898), and this would have meant in the Canal only 1⅜ knots per hour for less than a day, if allowed to flow freely. Pages 37, 38, 42.

The flood curves plotted give the data known in convenient form, including the probable curve for the flood of 1879. Page 38.

The lowest figure shows all the French results from 1893 to 1900, and the graphic expressions of the monthly, seasonal and yearly means. They must be read, however, and reckoned in the light of this demonstration of probable under gaging. The Mindi estimate is made by adding 77% to that of Bohio. Page 37.

PROJECT FOR PANAMA CANAL.
Régime of the Chagres River, Plate IX.

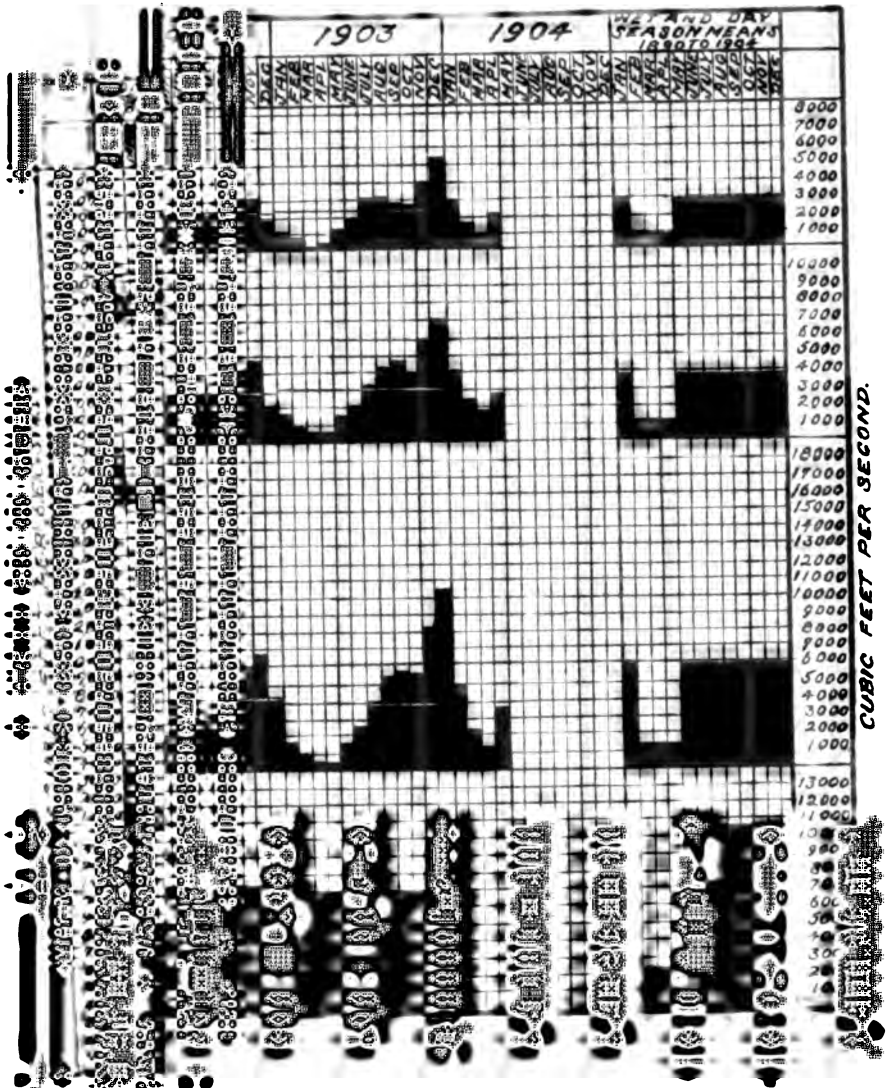

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PLATE X.

COMPARATIVE DAM PROFILES.

ROCK FILL EARTH DAMS ON ALLUVIAL FOUNDATIONS.

This plate shows the relative sections taken parallel to river flow, of various dams proposed. Those which the author regards as proper for the projects he advances are indicated. The others are for comparison.

Section of Dam with 90 *ft. head* represents the application of the Morison Dam principle necessary for a Bohio Dam to execute the Project of the Commission of 1901 on existing foundations. The plate shows the monstrous dimensions which, according to percolation formula, would be necessary. Pages 13, 82.

Masonry Core Earth Dam proposed for Bohio by Commission of 1901. The absence of rock foundations on which they counted has made this dam impossible. Pages 13, 71.

Section of Dam with 60 *ft. head* represents the size of dam necessary to execute the Comité Technique Plan, now that rock foundations are known not to be available. Pages 12. 82, 161.

Section of Dam 30 *ft. Head. Type for Mindi, Chagres, La Boca, Projects A, B, B'.* represent a proposed form of dyke, showing small head under low head system. Pages 14, 89, 92, 162.

Section of Dam with net 30 *ft. head.* This dam has a net head of 30 ft., i. e., the water is 30 ft. on one side and 60 ft. on the other. The comparatively small size and simplicity of this dam as compared with the Comité Technique Plan dam to give the same level, where the whole head of 60 ft. is on one dam, can be readily seen. Page 110.

Section of Dam with 30 *ft. head, Levels* $\frac{60}{90}$ *Bates Project B' at Bohio.* By this net head System, a level of 90 ft. is reached with no dam sustaining a head of over 30 ft. Pages 110, 114.

Relative Sections of Dams with 60' *full head and* 30' *net head.* This represents the effective difference between dams with the same formula of percolation using the high head system as against the low head system used in Projects B and B'. Pages 112, 114.

Relative Section of Dams with 90 *ft. full head and* 60 *ft. net head.* Shows the distinction between the possible dam for an 85' level on the Plan of the U. S. Commission of 1901, and the net head System. Pages 110, 82.

Proposed 120 *ft. Dam at Gatun.* Its unexampled size may be appreciated. Page 83.

PROJECT FOR PANAMA CANAL.

Comparative Dam Profiles, Plate X.

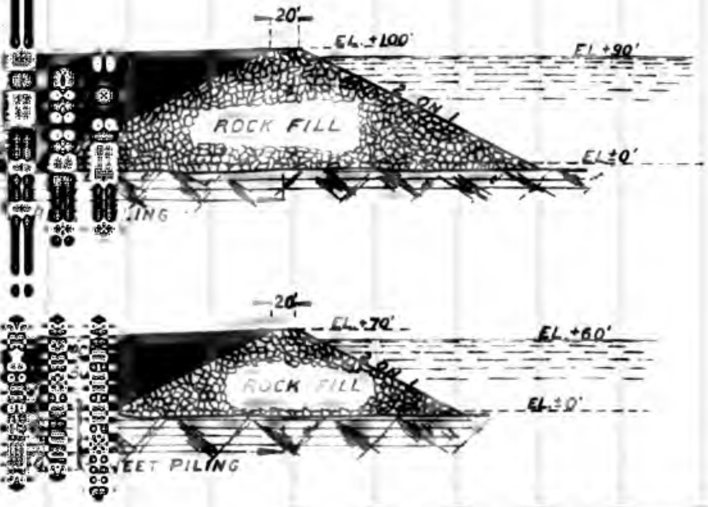

PLATE XI.

PROPOSED DAMS, DYKES AND LOCKS.

PROJECTS A, B AND B′

Mindi Barrage founded in the rock of Jaramillo Hill together with the atrium basin and the lock. Pages 22, 91, 96.

The possible Bohio Dam of 30 feet net head for Project B is shown, with the lock and spillway sites. Page 112.

The Gatun Dam which may be the main dam of Project B or may be the middle dam of Project B′. Pages 112, 114.

The Gatun Cut-off which shortens the canal 1.2 sea miles is available only for the terminal lake plans of the author. Any plan with sea-level ends must make deep cuttings or employ extra locks, carry the canal a long distance embanked. Page 83.

The Gamboa Dam site and Obispo Triangle. Pages 72, 75.

The Pedro Miguel Lock and By-Pass. The third lock of Project B being at Pedro Miguel, the Chagres water discharge must be arranged. A small stream makes a natural by-pass, so that the water is conducted around the lock and discharged into Lake Panama below. Page 113.

Barrages, locks and dykes at Panama. It is seen that the two structures for which rock foundations are desirable are founded in the rocky hill. Pages 23, 101.

PROJECT FOR PANAMA CANAL.

Proposed Dams, Dykes and Locks, Plate XI

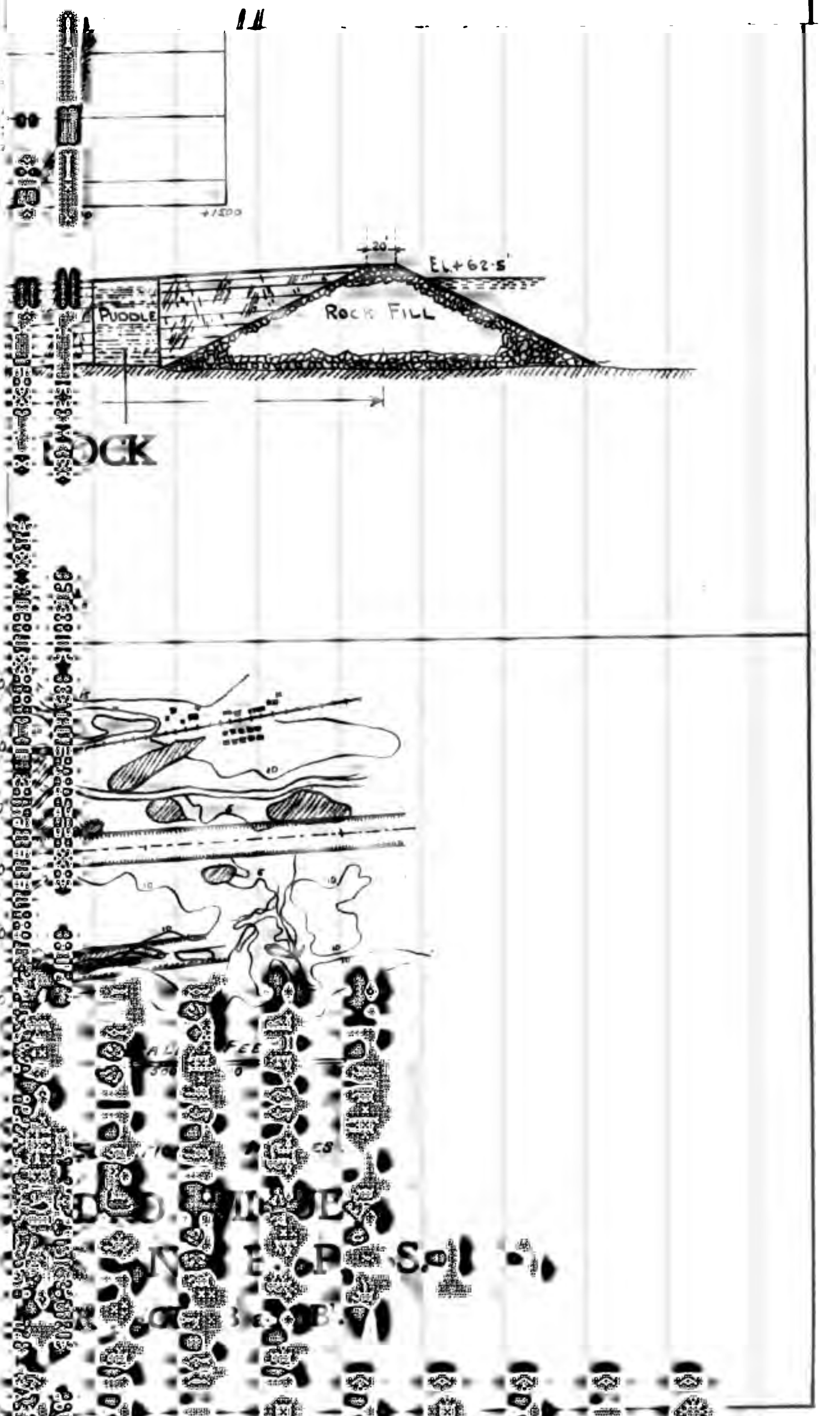

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PLATE XII.

TYPES OF DAMS AND BARRAGES.

MASONRY DAMS ON ROCK FOUNDATIONS.

The Assuan Dam is the model for the dams at Alhajuela, Gamboa and Cano, also for the barrages at Mindi and Sosa. The construction details are here given. Pages 71, 72.

A type of barrage used at Assuit, built of concrete and brick, in Nile River soil is inserted to show this structure's independence of rock foundations. Page 89.

The comparative profiles of the Masonry Dams proposed as compared with others and with dams of the Sea Level proposal. Pages 14, 72, 80, 162.

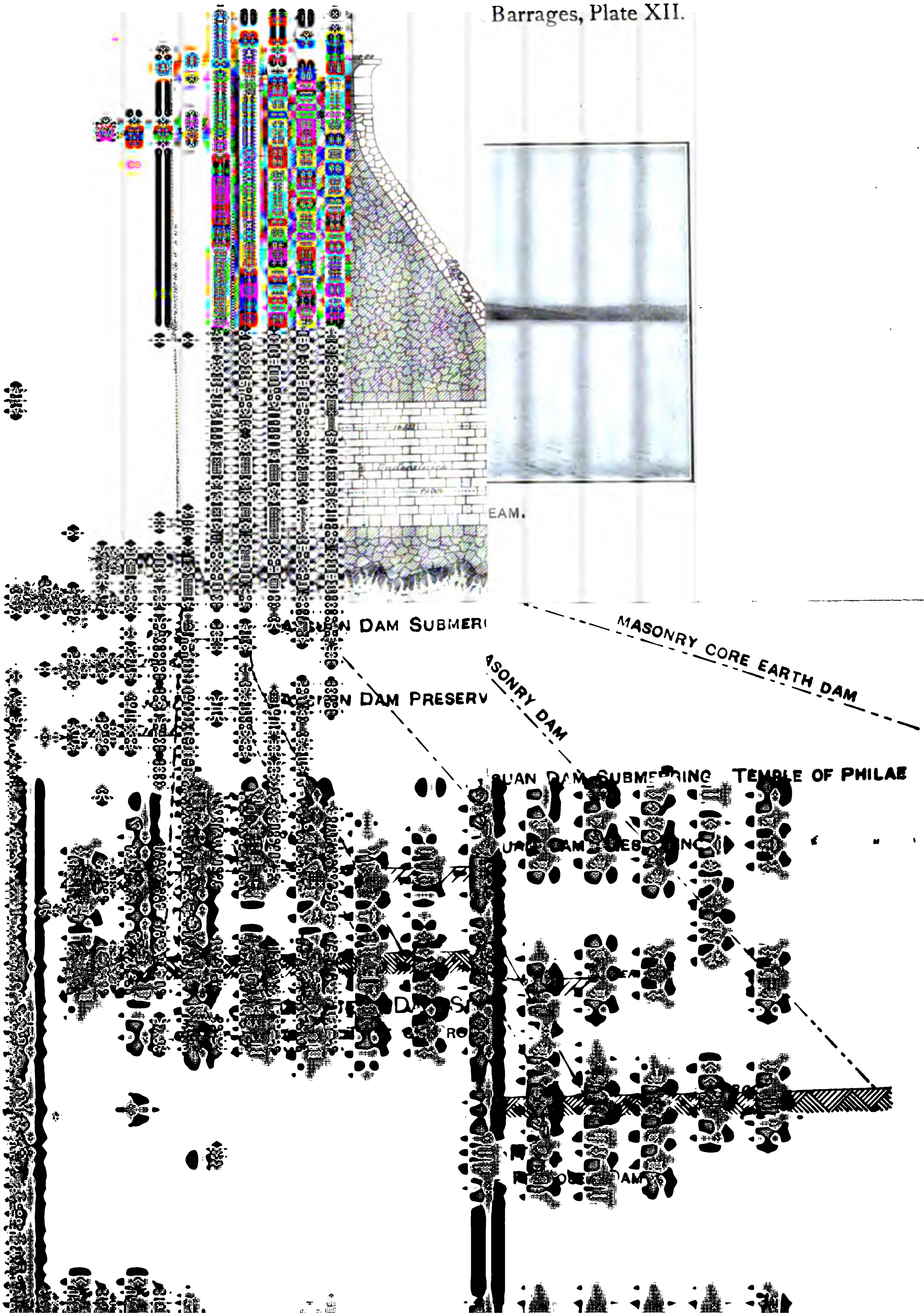

EAM.
DAM SUBMER
DAM PRESERV
MASONRY CORE EARTH DAM
ASONRY DAM
UAN DAM SUBMERGING TEMPLE OF PHILAE
DAM

PLATE XIII.

FINANCIAL DIAGRAMS.

The tonnage diagram gives an indication of the possible rate of tonnage increase on the Panama Canal, by the tonnage advance rate of other waterways. Page 144.

The Financial Prospect by the Business Method of estimating shows in regard to the canal: 1. The capital investment. 2. The earnings and expense ratios on a construction cost of $145,000,000. Page 142.

The Financial aspect by the Government Method shows similar relations, not counting interest on investment but following the course pursued in Irrigation expenditures. Page 145.

The financial relations of the authorized $145,000,000 expenditure and the Sea Level $230,500,000 are given and show how poor is an investment in a Sea-Level Canal. Page 152.

PROJECT FOR PANAMA CANAL.
Financial Diagrams, Plate XIII.

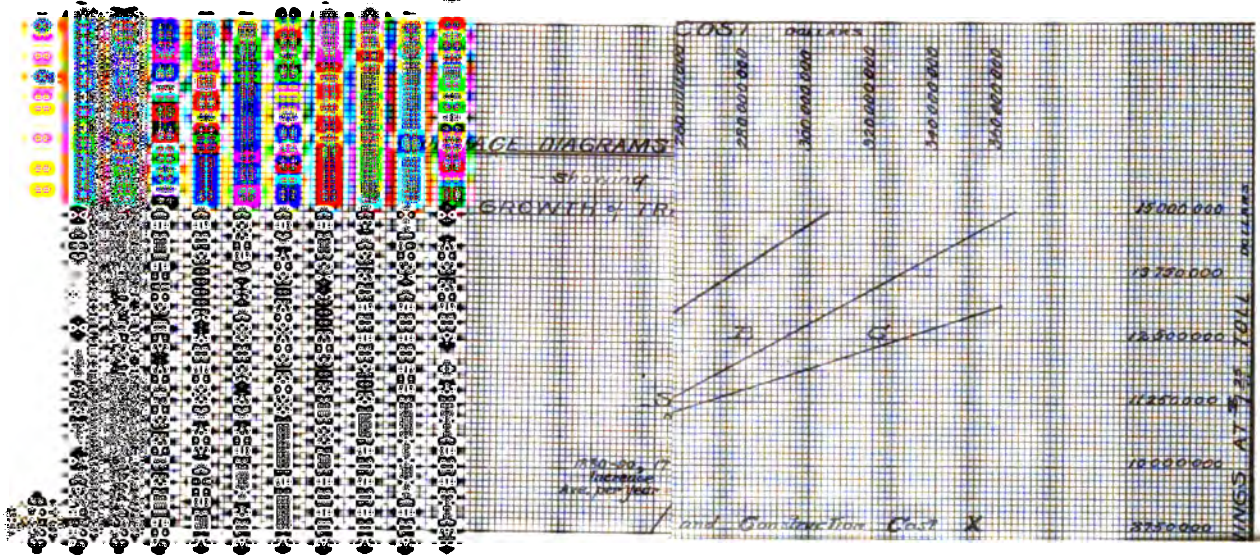


PLATE XIV.

CHANNEL SECTION DIAGRAMS.

Illustrate the growth of Merchant and War vessel dimensions and the relations of these to the Canal prism dimensions. Pages 13, 53, 55, 61, 161, 169.

PROJECT FOR PANAMA CANAL.
Channel Section Diagrams, Plate XIV.

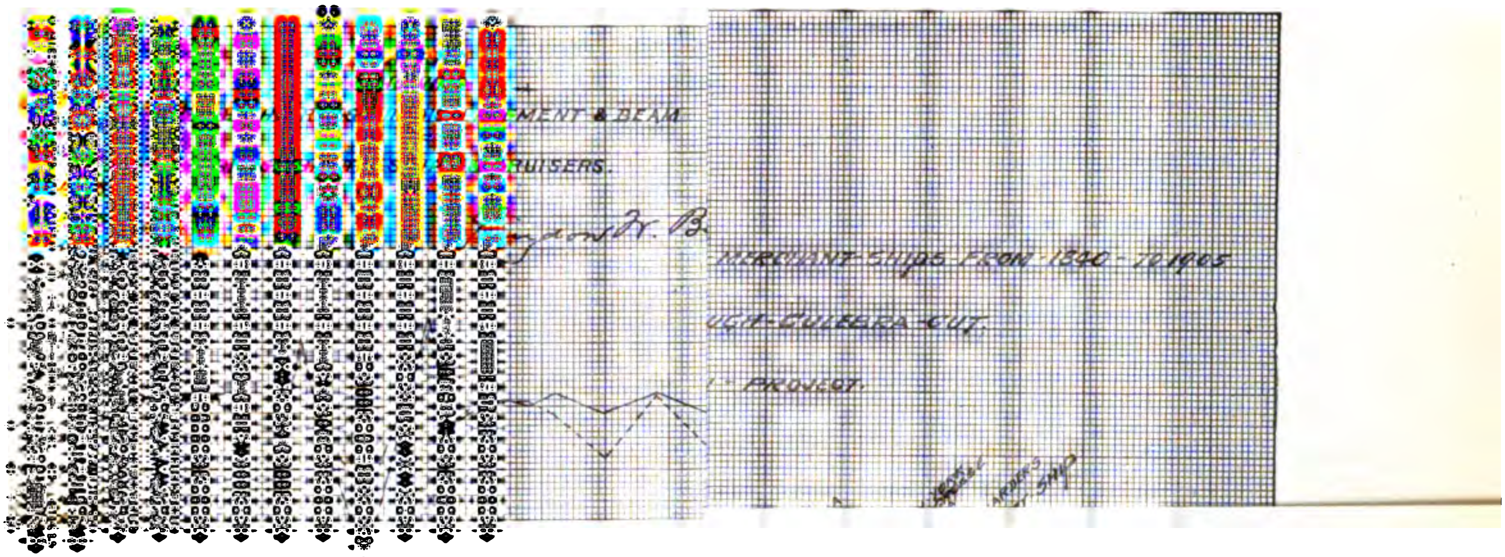
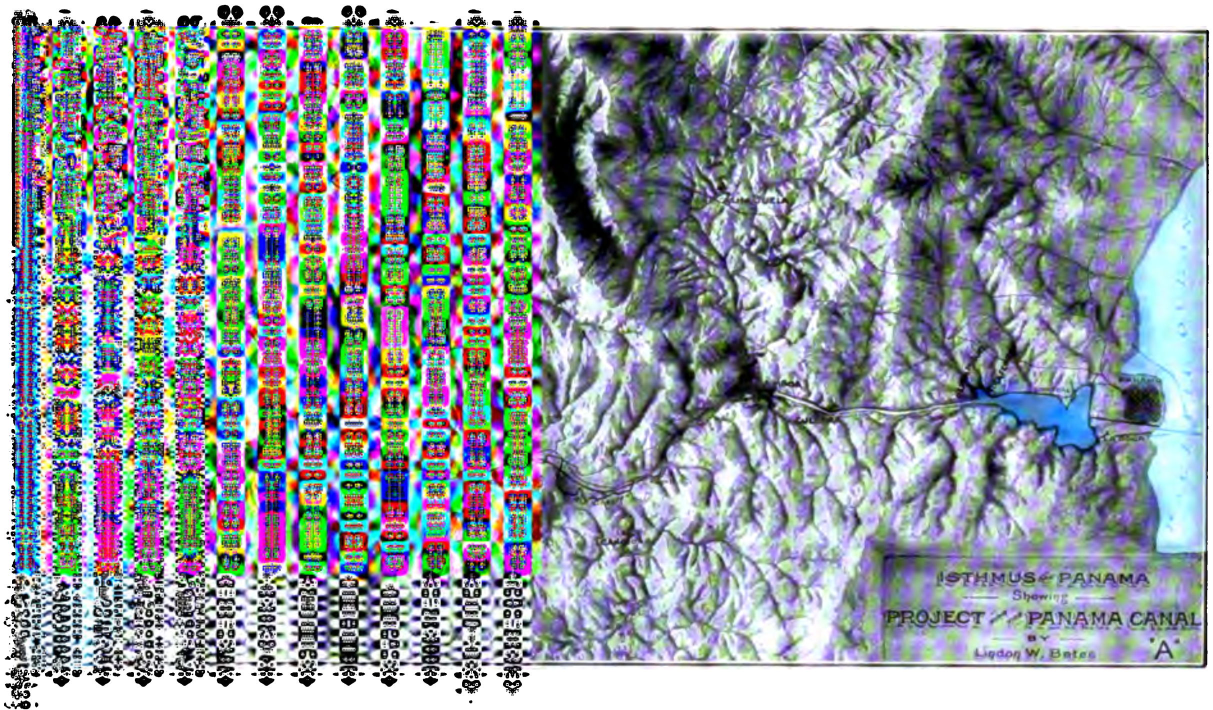
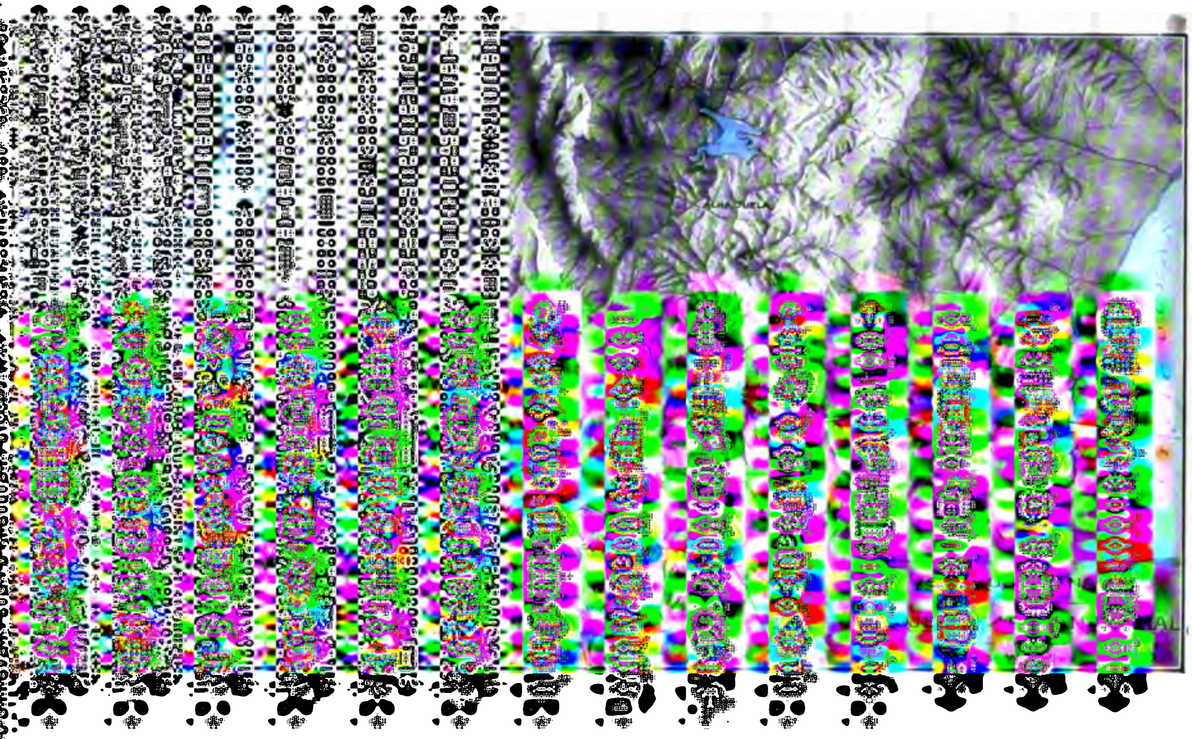


PLATE XV.

THE SIX CANAL PLANS.

In this plate are shown the lake dispositions of the six main canal plans that have been advanced. Pages 8, 12, 136, 164, 169.


ISTHMUS of PANAMA
Showing
PROJECT of PANAMA CANAL
BY
Lindon W. Bates
"A"



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